U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-254 015

Wastewater Treatment Technology Documentation for Endrin Manufacture

Midwest Research Inst.

Prepared For
Environmental Protection Agency

February 6, 1976

KEEP UP TO DATE

Between the time you ordered this report—which is only one of the hundreds of thousands in the NTIS information collection available to you—and the time you are reading this message, several *new* reports relevant to your interests probably have entered the collection.

Subscribe to the **Weekly Government Abstracts** series that will bring you summaries of new reports *as soon as they are received by NTIS* from the originators of the research. The WGA's are an NTIS weekly newsletter service covering the most recent research findings in 25 areas of industrial, technological, and sociological interest—invaluable information for executives and professionals who must keep up to date.

The executive and professional information service provided by NTIS in the **Weekly Government Abstracts** newsletters will give you thorough and comprehensive coverage of government-conducted or sponsored research activities. And you'll get this important information within two weeks of the time it's released by originating agencies.

WGA newsletters are computer produced and electronically photocomposed to slash the time gap between the release of a report and its availability. You can learn about technical innovations immediately—and use them in the most meaningful and productive ways possible for your organization. Please request NTIS-PR-205/PCW for more information.

The weekly newsletter series will keep you current. But *learn what you have missed in the past* by ordering a computer **NTISearch** of all the research reports in your area of interest, dating as far back as 1964, if you wish. Please request NTIS-PR-186/PCN for more information.

WRITE: Managing Editor
5285 Port Royal Road
Springfield, VA 22161

Keep Up To Date With SRIM

SRIM (Selected Research in Microfiche) provides you with regular, automatic distribution of the complete texts of NTIS research reports *only* in the subject areas you select. SRIM covers almost all Government research reports by subject area and/or the originating Federal or local government agency. You may subscribe by any category or subcategory of our WGA **(Weekly Government Abstracts)** or **Government Reports Announcements and Index** categories, or to the reports issued by a particular agency such as the Department of Defense, Federal Energy Administration, or Environmental Protection Agency. Other options that will give you greater selectivity are available on request.

The cost of SRIM service is only 45¢ domestic (60¢ foreign) for each complete microfiched report. Your SRIM service begins as soon as your order is received and processed and you will receive biweekly shipments thereafter. If you wish, your service will be backdated to furnish you microfiche of reports issued earlier.

Because of contractual arrangements with several Special Technology Groups, not all NTIS reports are distributed in the SRIM program. You will receive a notice in your microfiche shipments identifying the exceptionally priced reports not available through SRIM.

A deposit account with NTIS is required before this service can be initiated. If you have specific questions concerning this service, please call (703) 451-1558, or write NTIS, attention SRIM Product Manager.

This information product distributed by

NTIS U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

176125

MIDWEST RESEARCH INSTITUTE

PB 254 015

MRI REPORT

EPA-440/9-76-011

WASTEWATER TREATMENT TECHNOLOGY DOCUMENTATION FOR ENDRIN MANUFACTURE

FINAL REPORT
February 6, 1976

Contract No. 68-01-3524
MRI Project No. 4127-C

EPA Project Officer
Mr. Ralph H. Holtje

For

Office of Water Planning and Standards
U.S. Environmental Protection Agency
Waterside Mall, Room 2834
Mail Stop WH595
401 M Street, S.W.
Washington, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

MIDWEST RESEARCH INSTITUTE 425 VOLKER BOULEVARD, KANSAS CITY, MISSOURI 64110 • 816 561-0202

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-440/9-76-011	2.	3. Recipient's Accession No. PB254015
4. Title and Subtitle Wastewater Treatment Technology Documentation, Manufacture of Endrin			5. Report Date Pub. June 1976 6.
7. Author(s) A. F. Meiners, C. E. Mumma, T. L. Ferguson and G. L. Kelso			8. Performing Organization Rept. No. 4127-C
9. Performing Organization Name and Address Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110			10. Project/Task/Work Unit No. 11. Contract/Grant No. 68-01-3524
12. Sponsoring Organization Name and Address Office of Water Planning and Standards U.S. Environmental Protection Agency 401 M Street, S.W. Washington, D. C. 20460			13. Type of Report & Period Covered Interim Report, Edited 14.

15. Supplementary Notes

Some editing was performed by EPA.

16. Abstracts

This report was prepared to provide technologic supporting information for toxic pollutant effluent standards proposed by EPA under §307(a) of the Federal Water Pollution Control Act Amendments of 1972. The report identifies potential technologies, assesses implementation feasibility, estimates final effluent characteristics and estimates installation and operation costs for Endrin Manufacturers.

17. Key Words and Document Analysis. 17a. Descriptors

Wastewater
Waste Treatment
Cost Analysis
Cost Comparison
Pesticides
Manufacturers

17b. Identifiers/Open-Ended Terms

Toxic Pollutant Effluent Standards
Federal Water Pollution Control Act

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	UNCLASSIFIED	102
	20. Security Class (This Page) UNCLASSIFIED	22. Price $5.50

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

WASTEWATER TREATMENT TECHNOLOGY DOCUMENTATION FOR ENDRIN MANUFACTURE

by

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

FINAL REPORT
February 6, 1976

Contract No. 68-01-3524
MRI Project No. 4127-C

EPA Project Officer
Mr. Ralph H. Holtje

For

Office of Water Planning and Standards
U.S. Environmental Protection Agency
Waterside Mall, Room 2834
Mail Stop WH595
401 M Street, S.W.
Washington, D.C. 20460

PREFACE

This is one of four reports on pesticide-containing wastewaters prepared by Midwest Research Institute for the Office of Water Planning and Standards. These reports concern the wastewater treatment technology involved in the manufacture of aldrin/dieldrin, endrin, toxaphene, and DDT. This report is concerned with endrin.

These reports were prepared by Dr. Alfred F. Meiners, Mr. Charles E. Mumma, Mr. Thomas L. Ferguson, and Mr. Gary L. Kelso. This program (MRI Project No. 4127-C) has been under the general supervision of Dr. Edward W. Lawless, Head, Technology Assessment Section. Dr. Frank C. Fowler, President, Research Engineers, Inc., acted as consultant to the program.

Approved for:

MIDWEST RESEARCH INSTITUTE

L. J. Shannon

L. J. Shannon, Assistant Director
Physical Sciences Division

February 6, 1976

INTRODUCTION

Midwest Research Institute has performed a comprehensive examination of the wastewater treatment technology applicable to aldrin/dieldrin, endrin, DDT, and toxaphene. The work was performed for the Environmental Protection Agency under Contract No. 68-01-3524.

The basic objectives of the program were: (a) to perform an examination of the wastewater management practices currently employed in the manufacture of the specified pesticide; (b) to examine the state of the art of potential wastewater treatment processes that might be applicable to this industry; and (c) to select those processes that would be applicable to EPA toxic pollutant control technology requirements. Of special interest was the cost of existing and proposed wastewater treatment methods.

This report concerns the wastewater treatment technology for endrin manufacture.

CONTENTS

		Page
List of Figures		v
List of Tables		vi
	ENDRIN MANUFACTURE	
Sections		
I	Summary	1
II	Manufacture	7
	Characterization of Industry	7
	Manufacturing Process	8
	Wastewater Characteristics	12
	In-Plant Controls	16
III	Wastewater Treatment Methods	18
	Present Treatment System	18
	Alternate Treatment Systems	19
	Effluent Quality Achievable Using Alterante Treatment Systems	25
IV	Wastewater Treatment Cost Estimates	31
	Description of Alternate Treatment Systems	31
	Estimated Capital Investment Costs for the Resin Adsorption System and the Reductive Degradation System	38
	Annual Operating Costs for the Resin Adsoption System and the Reductive Degradation System	50
	Total Cost Estimates for the Resin Adsorption System and the Reductive Degradation System	59
	Carbon Adsorption Process Costs	59
	References	75
Appendix A	Definition of Terms and Discussion of Conventional Engineering Practices Used in Estimating Costs of Pesticide Wastewater Treatment Processes	

FIGURES (concluded)

No.	Title	Page
PART B - TOXAPHENE FORMULATION		
1	Large Formulation Plant Locations.	123
2	Product Distribution for Large Formulation Plants. . . .	125
3	Distribution of Plants by Age.	127
4	Liquid Formulation Unit.	132
5	Typical Sulfur Grinding Unit	134
6	Process for Formulating Dust	136
7	Toxaphene Formulation Plants (1973).	139
8	Formulation Plants Using Evaporative Treatment Systems .	157
9	Pretreatment-Filtration-Adsorption Systems	168

FIGURES

No.	Title	Page
	ENDRIN MANUFACTURE	
1	Production and Waste Schematic for Endrin	10
2	Conceptual Flow Diagram of a Resin Adsorption System for the Treatment of Endrin Wastewater.	32
3	Conceptual Flow Diagram of a Reductive Degradation System for the Treatment of Endrin Wastewater.	33
4	Conceptual Flow Diagram of a Resin Adsorption System and a Reductive Degradation System in Series for the Treatment of Endrin Wastewater.	34
5	Conceptual Flow Diagram of an Activated Carbon Adsorption System for the Treatment of Endrin Wastewater	35

TABLES

No.	Title	Page
1	Summary of Costs for Endrin Wastewater Treatment Systems (1975, $)	6
2	Effluent Limitations Guildelines for Halogenated Organic Pesticides (Tentative Recommendations)	30
3	Installed Capital Equipment Cost for the Resin Adsorption System, The Reductive Degradation System, and The Two Systems in Series	51
4	Total Investment Cost and Annual Operating Cost for Three Endrin Wastewater Treatment Systems Treating Either 300 or 600 Gal/Min Wastewater Effluent	60
5	Installed Capital Equipment Cost for the 300 GPM Carbon Adsorption System	73
6	Estimated Total Investment and Annual Operating Costs for Granular Activated Carbon Adsorption Systems (300 gpm Endrin Wastewater Flow Rate)	74

Appendix A

A-1	Estimating Information Guide	A-3

ENDRIN MANUFACTURE

SECTION I

SUMMARY

The Velsicol Chemical Corporation is currently the sole manufacturer of endrin in the United States and produces endrin only at its plant at Memphis, Tennessee. Data on the plant capacity and current production rate are not available, but the estimated production for 1975 is 6 million pounds of endrin.

The manufacture of endrin results in the production of both process wastewaters and cooling waters that are contaminated with endrin. In May 1975, two direct discharges into Cypress Creek totaled 1,031 gpm (gallons per minute). The discharge on the NW Branch contained 0.002 lb of endrin per day at a concentration of 2 ppb. The discharge on the SW Branch contained 0.071 lb of endrin per day at a concentration of 6 ppb. In the same period, the Velsicol discharge to the Memphis Municipal Sewage System averaged 2,483 gpm (3.576 million gallons per day) at an endrin concentration of 81 ppb and contained 2.429 lb of endrin per day. The total wastewater discharge from the Velsicol plant averaged 3,514 gpm and contained an average of 2.5 lb of endrin per day.

Velsicol is presently involved in an extensive effort to reduce water usage and to separate the noncontact cooling waters from the process wastewaters in order to minimize the amount of contaminated water that will require treatment. Velsicol expects eventually to reduce the amount of contaminated water to about 150 gpm or less.

The present wastewater treatment system consists of sedimentation, sand filtration, fine cartridge (2 μ mesh) filtration, and neutralization. The treated wastewater is then discharged into the municipal sewer system.

The present treatment system is capable of compliance with the effluent limitation guidelines and regulations (suspended solids, BOD and pH) issued under Section 306 of P.L. 92-500.

In the present system, sedimentation takes place in a sump which is equipped to remove floatable, tar-like material as well as sludge. The floatables and sludge removed from the sump are incinerated onsite in a natural gas-fired incinerator equipped with an exit gas scrubber to scrub out the hydrogen chloride produced during incineration. The acidic water from the scrubber goes to a neutralization pit prior to entering the city sewer system.

The wastewater which is discharged from the sump is saturated with endrin and contains other contaminants. This wastewater stream contains 300 ppb endrin, 400 ppm carbon tetrachloride, 30 to 50 ppb hexachloronorbornadiene, and 30 to 50 ppb heptachloronorbornene.

This report examines in detail four wastewater treatment systems that have promise of effectively reducing the concentration of endrin and the daily load. These are: (a) resin adsorption, (b) reductive degradation, (c) resin adsorption and reductive degradation in series, and (d) activated carbon adsorption.

Extensive laboratory experiments have shown the feasibility of the above systems although there is no prior experience in applying these systems to endrin-contaminated wastewater. The first three systems are under laboratory pilot plant study at the site. This is a Velsicol/EPA supported grant project to ascertain process feasibility, scale up design factors, and achievable effluent quality. The pilot-scale studies are expected to be on stream early in 1976; however, at least 6 months will probably be required to obtain significant data.

The activated carbon system is not under study at the site, but technology is available in other industries and is probably transferable. Laboratory isotherm data for endrin are available and endrin contaminated lake water has been treated using a temporary system operating in a flow range of 175 to 198 gpm. This system reduced the endrin content from 6.7 ppb (influent concentration) to less than 0.05 ppb (effluent concentration).

The resin adsorption system would use a patented synthetic polymeric adsorbent which can be regenerated with recovery of the pesticide. The resin adsorption pilot plant at Velsicol has a capacity of 100 gpm. At a presumed full scale wastewater flow rate of 300 gpm, the process has

the potential of reducing the effluent concentration down to 1.4 ppb (0.0049 lb/day) endrin at an amortized annual operating cost of $2.87/ 1,000 gal. of wastewater.

The reductive degradation system would use a packed column of copper-catalyzed iron to decompose chlorinated hydrocarbon pesticides. A 100 gpm pilot plant will be operated at the Velsicol site in parallel (or in series) with the resin adsorption system. At a presumed full scale wastewater flow rate of 300 gpm, the reductive degradation process has the potential of reducing the effluent concentration to 1.0 ppb (0.0036 lb/day) endrin at an amortized annual operating cost of $1.20/1,000 gal. of wastewater.

The special capabilities of the resin adsorption system and the reductive degradation system may be utilized by placing the processes in series. It is anticipated that the two systems in series would produce a higher quality effluent than would be achievable by either process operating singly. At a presumed full scale wastewater flow of 300 gpm, the series arrangement has the potential of reducing the effluent concentration down to 0.1 ppb (0.00036 lb/day) endrin at an amortized annual operating cost of $3.55/ 1,000 gal. of wastewater.

The fourth treatment system would use activated carbon. A full scale 300 gpm plant having a 30 min carbon contact time has the potential of reducing the effluent concentration down to less than 2 ppb endrin at an amortized annual operating cost of $1.35/1,000 gal. of wastewater. Activated carbon adsorption might also be considered as a polishing process following either the resin adsorption system or the reductive degradation system.

Following is a summary table of the estimated installed capital equipment costs and annual operating costs for the four treatment systems described above. The cost of each system is estimated at two different wastewater flow rates--300 gpm and 600 gpm--to provide a cost range for each system. The associated unit operating cost per 1,000 gal. of wastewater and per pound of endrin produced is estimated for each treatment system. Assumptions made in determining the costs shown in the table are given in detail in the report.

Table 1. SUMMARY OF COSTS FOR ENDRIN WASTEWATER TREATMENT SYSTEMS (1975, $)

Treatment system	Wastewater flow rate (gpm)	Endrin in treated effluent ppb	Endrin in treated effluent lb/day	Installed capital equipment cost, $	Annual operating cost, $	Cost per 1,000 gal. wastewater	Cost per pound of endrin produced, $
Resin adsorption	300	1.4	0.0049	770,000	433,200	2.87	0.072
	600	1.4	0.0098	1,260,000	741,300	2.45	0.124
Reductive degradation	300	1	0.0036	433,000	181,800	1.20	0.030
	600	1	0.0072	631,000	249,000	0.82	0.042
Resin adsorption plus reductive degradation	300	0.1	0.00036	954,000	537,200	3.55	0.090
	600	0.1	0.00072	1,541,000	889,700	2.94	0.148
Activated carbon adsorption:							
30 min contact time	300	< 2	< 0.0072	692,000	204,000	1.35	0.034
60 min contact time	300	< 2	< 0.0072	870,000	242,000	1.60	0.040

SECTION II

MANUFACTURE

CHARACTERIZATION OF INDUSTRY

General

The Velsicol Chemical Corporation Plant at Memphis, Tennessee, is currently the sole manufacturer of endrin in the United States. Shell Chemical Corporation formerly manufactured endrin at its Denver, Colorado, plant, but ceased production in 1963. Velsicol has been producing endrin for over 20 years. Information on the production capacity is not available.

Velsicol manufactures 95% technical endrin by using a Diels-Alder reaction of hexachlorocyclopentadiene with vinyl chloride. The plant operates 24 hr/day, 7 days/week, and maintains a fairly steady production rate throughout the calendar year (Vitalis, 1975). The 1975 production volume is estimated (on the basis of general knowledge of endrin use patterns) to be in the range of 3 to 6 million pounds. The higher figure has been used in this report as a basis of cost calculations.

Endrin is formulated into various products by numerous formulators. The most common formulation is an emulsifiable concentrate containing 1.6 lb of endrin per gallon. Dusts and granules (2% endrin) are also formulated in small quantities.

Endrin is used principally for the control of insects on cotton and certain other field crops.

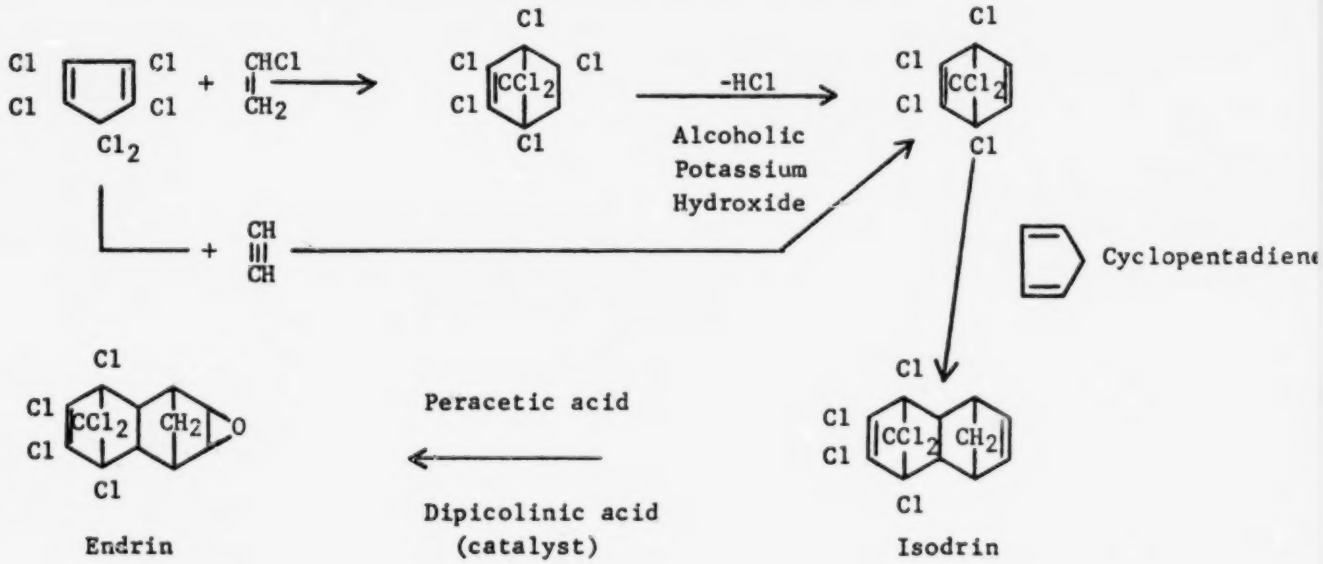
MANUFACTURING PROCESS

Endrin is 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene. It is a stereo-isomer of dieldrin (Ferguson and Meiners, 1974).

The first step in endrin manufacture is a Diels-Alder reaction of hexachlorocyclopentadiene with vinyl chloride. According to Vitalis (1975) this reaction is almost stoichiometric resulting in a high yield, probably 96% of theory. The resulting product is dehydrochlorinated with ethanolic potassium hydroxide. The product is further reacted with cyclopentadiene to provide an intermediate compound, isodrin. Isodrin is then oxidized with peracetic acid to produce the epoxide, endrin (Vitalis, 1975).

Alternatively, a slightly more straightforward process may be practiced involving condensation of hexachlorocyclopentadiene with acetylene to give the intermediate which may then be condensed with cyclopentadiene and epoxidized to give endrin.

The various steps in endrin manufacture are as follows:

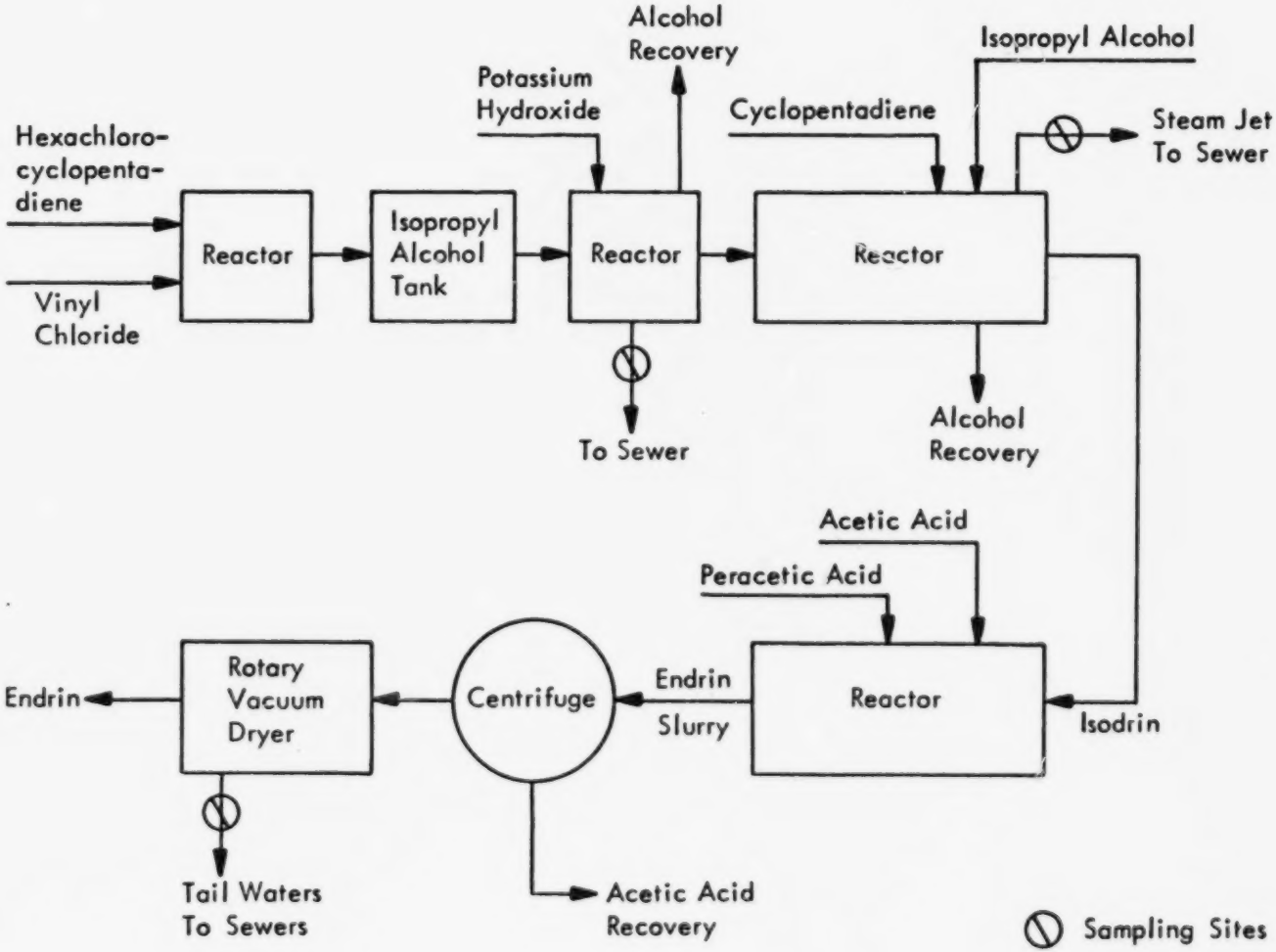


The production and waste schematic for endrin are shown in Figure 1 (Cywin, 1975).

The following reaction conditions are described by H. Bluestone in U.S. Patent 2,676,132 (April 20, 1954) (to Shell Development Company).

Temperature: The acetylene-hexachlorocyclopentadiene condensation is carried out, preferably, in the range of 150 to 175°C. The second stage condensation with cyclopentadiene is carried out at 50 to 90°C. This reaction is exothermic. The final epoxidation step, which is mildly exothermic, is conducted at 20 to 45°C.

Pressure: In the condensation of acetylene and hexachlorocyclopentadiene, the preferred operating range is from 2,000 to 4,000 psi. The second stage condensation with cyclopentadiene is carried out at atmospheric pressure, as is the final epoxidation step.



Source: Cywin (1975)

Figure 1. Production and waste schematic for endrin.

Reaction time: Contact times in the Diels-Alder condensation with acetylene is usually from 0.5 to 3.0 hr. The second stage of endrin preparation, the condensation with cyclopentadiene, involves a 2 hr reaction period following completion of gradual reactant addition. The epoxidation step is fairly slow. After slow reactant addition, the mixture is agitated at length and finally heated to 45°C for about 1 hr.

Reaction medium: The condensation of acetylene with hexachlorocyclopentadiene is carried out in the homogeneous liquid phase in the absence of any solvent other than the hexachlorocyclopentadiene. The second stage condensation with cyclopentadiene is also conducted in the liquid phase in the absence of any added solvent. A benzene solvent is used in the final epoxidation step.

Catalyst: No catalyst is employed either in the Diels-Alder condensation of hexachlorocyclopentadiene with acetylene, or in the subsequent Diels-Alder condensation of the product of the first reaction with cyclopentadiene. The epoxidation reaction may be carried out in the absence of a catalyst or a catalyst may be used.

Product recovery: The Diels-Alder reaction mixture from the acetylene reaction is passed to a suitable product separator. The reaction mixture from the second stage of endrin preparation is cooled, whereupon the product begins to precipitate out. The mixture is poured into a suitable solvent (for example, boiling acetone-methanol mixture) and then crystallized therefrom.

After the final epoxidation step, the reaction mixture may be steam distilled to remove excess peracid, carboxylic acid and benzene solvent. The residue may be ether extracted and the ether solution washed and dried. The ether may then be evaporated to give the final endrin product in crystalline form.

Improved epoxidation procedure: A process developed by D. R. Marks; U.S. Patent 2,899,446; August 11, 1959; assigned to Velsicol Chemical Corporation, provides an improved technique for endrin manufacture. The Bluestone Patent (U.S. Patent 2,676,132, summarized above) describes a process for the preparation of endrin in which the last step is the oxidation of isodrin with peracetic acid. This step, if performed in the absence of impurities and under optimum conditions, produces high yields of a relatively pure product (95 to 100%). However, when this oxidation is run in the presence of metallic contamination, serious difficulties are encountered, in that several undesired side products are produced, the product is of low purity and it is rendered somewhat unstable. Marks found that this problem can be solved by the addition of dipicolinic acid in the production of endrin. Dipicolinic acid is meta-2,6-pyridine dicarboxylic acid.

WASTEWATER CHARACTERISTICS

The manufacture of endrin results in the production of both process wastewaters and cooling waters that are contaminated with endrin (Vitalis, 1975). At the present time, cooling waters are discharged into the nearby

Cypress Creek, and the process wastewaters are discharged into the Memphis Municipal Sewage System following treatment (Vitalis, 1975).

Ferguson and Meiners (1974) provided information concerning wastewater characteristics obtained from a report, "Endrin Pollution in the Lower Mississippi River Basin," prepared by the Federal Water Pollution Control Administration and the U.S. Department of the Interior, September 1967, reporting the investigations of fish kills in 1963 and 1964:

1. Based upon results obtained during 31 weeks of sampling (January 1965 to February 1967) the Velsicol process wastes contained an average of 179.45 ppb of endrin with values ranging from 0 to 12,133 ppb. Discharge flows in the period averaged 3,190 gpm (7.1 cfs) with a range of 314 to 10,400 gpm (0.7 to 23.2 cfs). The average endrin load discharged was calculated to be 7.09 lb/day.

2. The mean concentration of endrin in 215 grab samples of cooling water taken in the period January 1965 to February 1967 was reported to be 10.67 ppb. Flows averaged less than 449 gpm (1 cfs). Endrin loads ranged from 0 to 0.75 lb/day with an average of 0.5 lb/day.

3. The average endrin concentration was 60.86 ppb in sanitary wastes in a 33 in. municipal sewer that received Velsicol sanitary wastes during the July 1965 to April 1966 period. Flow measurements indicated an average daily load of 1.20 lb/day of endrin.

4. Corrective measures were taken to reduce flows and concentrations in these discharges in an attempt to reach consistent concentrations of less than 168 ppb as a pollution control goal.

a. Velsicol's monitoring program showed the following discharges:

June 1973 average daily endrin discharge of 1.3 lb

May 1973 average daily endrin discharge of 1.4 lb

April 1973 average daily endrin discharge of 4.9 lb

March 1973 average daily endrin discharge of 2.4 lb

b. In 1973, Velsicol was in the process of reworking water distillation and usage in an effort to achieve 1 lb/day endrin average.

c. Independent engineering personnel have assisted Velsicol in the development of a solvent extraction procedure to reduce endrin discharges.

A summary of a telephone conversation between Ralph Holtje, EPA, Washington, and Charles Brouils, EPA, Atlanta, Georgia, on September 25, 1973, has been reported by Ferguson and Meiners (1974). This conversation revealed the following:

1. Velsicol was at that time under a 180 day order to meet 1 lb/day endrin limit in its discharge to the Memphis publicly owned sewage system.

2. The current treatment was lime neutralization, and settling prior to discharge. Noncontact cooling water went to the river.

3. Velsicol was considering use of a Rohm and Haas ion exchange resin said to be capable of reducing effluent concentration levels to 1 to 2 ppb.

On August 1, 1973, W. Robb Nisbet, Vice President, Manufacturing and Engineering, Velsicol Chemical Corporation, submitted a letter to Dr. C. H. Thompson of EPA. Ferguson and Meiners (1974) provided a summary of this letter:

1. At the current effluent flow (1973), a permissible limit of 168 ppb amounts to 5.0 lb of endrin per day discharged.

2. An EPA survey in February 1972, resulted in setting an effluent objective of 1 lb endrin per day to be in effect by December 31, 1974. According to Vitalis (1975), this objective was presented in a joint National Field Investigation Center in Denver and Region IV EPA Report on "Evaluation of Industrial Waste Discharges at Velsicol Chemical Company, Memphis, Tennessee," April 1972 (p. 21).

The endrin process wastewater has been analyzed by Envirogenics Systems Company (May and September 1974). They have found that the concentration of endrin in the process wastewater prior to treatment varies between 100 and 1,500 ppb with an average value of about 700 ppb. They estimated that the suspended solids content of the stream ranged from 500 to 800 ppm.

In May 1975, the total water discharge at Velsicol was reported (Vitalis, 1975) to average 3,514 gpm and to contain an average of 2.5 lb endrin per day. The quantity of endrin in the wastewater presently discharged by Velsicol

was determined by analyzing daily samples of three wastewater streams. These data are shown below.

Stream No.	Average May flow (gpm)	Average of May pH readings	Average endrin concentration (ppb)	Lb/day
1	65	10.6	2	0.002
2	966	10.9	6	0.071
3	2,483	11.4	81	2.429
	3,514			2.502

Stream No. 1 is discharged into Cypress Creek NW and contains surface runoff from the north side of the plant (chlor-alkali area) and cooling water. Stream No. 2 is discharged into Cypress Creek SW and contains surface runoff from the south side of the plant and cooling water. Stream No. 3 is discharged into the Memphis Municipal Sewage System and contains most of the process wastewaters from the plant as well as cooling water.

IN-PLANT CONTROLS

Velsicol is presently involved in an extensive effort both to reduce the water usage and to segregate the noncontact cooling waters (by diversion into Stream No. 2) from the process wastewaters in order to minimize the amount of contaminated water that will require treatment. According to Vitalis (1975) one method of reducing water usage will involve elimination of "water hogs" such as the steam jet barometric condenser units and replacing them with vacuum pumps.

Dr. Robert R. Swank, Jr., Acting Chief, Industrial Pollution Branch, EPA, Southeast Environmental Research Laboratory, Athens, Georgia, described some of the efforts made by Velsicol to reduce wastewater flow (Swank, 1975). At one time, all drains at the Velsicol plant were connected to the same sewer. A major effort has been made to disconnect and reconnect drains in order to segregate the heptachlor and endrin wastewater discharges from other wastewater discharges. This segregation will allow the heptachlor wastewater and the endrin wastewater to be treated individually. According to Swank (1975), the cost of achieving this segregation will be between $0.5 and $1 million.

SECTION III

WASTEWATER TREATMENT METHODS

PRESENT TREATMENT SYSTEM

In September 1973, the wastewater at the Memphis plant was being neutralized with lime, the solids were then allowed to settle, and the water was discharged (Ferguson and Meiners, 1974). The present treatment involves sedimentation and filtration (Swank, 1975) with ultimate discharge to the Memphis Municipal Sewer System.

According to Swank (1975), Velsicol has made a major effort to develop pretreatment facilities including a filtration system and a sump. Swank (1975) estimates that the cost of these pretreatment facilities was over $1 million. The present Velsicol wastewater system includes a sand filter and a fine cartridge filter (stainless steel, about 2 μ mesh). These two filters are backwashed periodically into the sump. According to Vitalis (1975), this sump is constructed of acid brick and is 20 ft x 30 ft x 15 ft deep. Swank (1975) stated that the sump, which has about an 8 day retention capacity, is equipped with (a) a skimmer bar at the top to remove tar-like material which is incinerated and (b) a sludge-collecting section in the

bottom. Swank (1975) estimates that the cost of the sump was $100,000. The sludge is also sent to an incinerator which is located on-site. Because of the nature of this sump operation, all water leaving the sump is saturated with endrin. According to Swank (1975) the solubility of endrin is about 300 ppb. According to Swank (1975), this stream also contains about 400 ppm carbon tetrachloride, 30 to 50 ppb hexachloronorbornadiene and 30 to 50 ppb heptachloronorbornene. Velsicol expects eventually to reduce the flow of this stream down to about 150 gpm or less.

According to Vitalis (1975), the incinerator is natural gas-fired and is equipped with an exit gas scrubber which contains 1-1/2 in. stoneware packing. Hydrogen chloride produced during the incineration of chlorinated hydrocarbon wastes is scrubbed out of the exit gases with water. The acidic water from the scrubber goes to a neutralization pit prior to entering the city sewer system.

ALTERNATE TREATMENT SYSTEMS

Many treatment systems have been investigated for removing endrin from wastewater. A detailed consideration of all these systems would be beyond the scope of this report. We have examined in detail the four treatment systems that have shown the greatest promise of becoming effective and economical methods of reducing the concentration of endrin in wastewaters.

Two of these systems have been investigated extensively in the laboratory, and are currently nearing pilot-stage testing; these are the resin adsorption system and the reductive degradation system. The Velsicol Chemical

Corporation is studying these systems under an EPA grant (EPA Demonstration Grant 803159-01). The Envirogenics Systems Company of El Monte, California, is also working on this grant as a subcontractor to Velsicol. Velsicol is studying the resin adsorption system and Envirogenics is examining the reductive degradation system.

A third system involves a combination of the above two treatment methods. Recent developments have indicated that the two systems may be more effective when operated in series (Swank, 1975).

The fourth system considered in this report is adsorption on carbon. Carbon is the most widely used adsorbent for removing contaminants from water and adsorption on carbon would likely become the treatment method of choice if the resin adsorption system does not prove to be feasible.

These alternate treatment systems are described below. The quality of the effluent that can be obtained from each system and the costs of each system are discussed in separate sections of this report.

Resin Adsorption System

The Rohm and Haas Company has developed a synthetic, polymeric adsorbent which shows excellent promise for the removal of pesticides from wastewater. According to this process (Kennedy, 1973) pesticides are adsorbed on Amberlite XAD-4, a recently developed synthetic, polymeric adsorbent possessing high porosity (0.50 to 0.55 ml of pore/ml of bead), high surface area (850 m^2/g) and an inert, hydrophobic surface. The adsorbent is regenerated with an organic solvent, and the adsorbed pesticides are recovered in a concentrated form.

The process appears to have important advantages over carbon adsorption. For example, the XAD-4 resin is superior to activated carbon both in terms of pesticide leakage and in overall operating capacity.

Although the laboratory data look promising, several problems must be worked out before a practical process can be operational. These problems include a determination of (a) the necessity for prefiltration of the resin column feed, (b) optimum flow rate, (c) optimum pH of the feed, (d) optimum resin column height, (e) bed life of resin before regeneration, and (6) the flow resistance of the bed.

The Amberlite XAD-4 resin adsorption system is presently being studied by Velsicol Chemical Corporation. To date the work has been done on a laboratory scale. A pilot plant unit (100 gpm flow rate capacity) has been designed, and installation of the unit at the Memphis plant is scheduled to begin in November 1975. According to Dr. Robert Swank (1975), EPA project monitor for this study, the concrete pad has been poured and the unit should be on-stream early in 1976.

Reductive Degradation System

Promising laboratory results have been shown by a degradation process involving the catalyzed reduction of chlorinated pesticides to relatively nontoxic products which do not contain chlorine. The process consists of a copper-catalyzed reduction of the pesticide in water by iron. The pesticide-containing wastewater is passed through a packed column with the reductant suitably diluted with inert particles to obtain good flow properties.

This process appears to be attractive for the destruction of a wide range of chlorinated hydrocarbon pesticides, including endrin and other cyclodiene pesticides (Sweeny and Fisher, 1970; Sweeny and Fisher, 1973). In laboratory studies, the process was found to proceed smoothly at ambient temperatures to remove all or a substantial amount of the chlorine from dissolved pesticides.

In a laboratory test using a column reactor, a solution containing 30 ppb of endrin was prepared and passed through the column. The pH was adjusted to 7.0 and the solution passed through the column at about 165 ml/min. Endrin was not observed in the effluent at the limit of detection used in the test (< 0.1 ppb). Unidentified product peaks were observed, however. The identity of these products is under study at the time of this report. Although no detailed information is presently available, it is believed that these products contain very little chlorine and are very volatile compared to endrin (Swank, 1975).

Additional laboratory studies of this system have been in progress for about 1 year. The system is being studied by the Envirogenics Systems Company. A pilot plant unit (100 gpm flow rate capacity) has been designed, and installation of the unit at the Memphis plant is scheduled to begin in November 1975. According to Dr. Robert Swank (1975), EPA project monitor for this study, the concrete pad has been poured and the unit should be on-stream early in 1976.

Resin Adsorption System Combined with Reductive Degradation System

The combination of the resin adsorption system with the reductive degradation system constitutes a third alternate treatment system. There are indications that the two systems could be operated effectively in series; the first stage would be absorption of most of the endrin on the synthetic resin, the second stage would be reductive degradation of a substantial amount of the remaining pesticide.

The two pilot-scale units being installed at Velsicol are constructed so that they can be operated in series or in parellel (Swank, 1975).

Adsorption on Carbon

Considerable laboratory data are available concerning the adsorption of endrin on activated carbon (Robeck et al., 1965; Hager and Rizzo, 1974). Also, endrin has been removed from water on a relatively large scale (175 to 198 gpm) in a program designed to remove endrin from a contaminated lake (Ryckman et al., 1971). In this study, the endrin concentration was reduced from 6.7 ppb to less than 0.05 ppb.

Isotherm Data - Robeck et al. (1965) and Hager and Rizzo (1974) have prepared isotherm data for the adsorption of endrin on carbon. The adsorption isotherm is the relationship, at a given temperature and other conditions, between the amount of a substance adsorbed and its concentration in the surrounding solution. A reading taken at any point on an isotherm gives the amount of material adsorbed per unit weight of carbon. In very dilute solutions, such as wastewater, a logarithmic isotherm plotting usually yields a straight line.

From adsorption isotherm data, a determination can be made of whether or not a particular degree of organic removal can be effected by adsorption alone. Isotherm data will also show the approximate adsorptive capacity of the carbon for the application. Isotherm data also afford a convenient means of studying the effect of pH and temperature on adsorption. Isotherms obtained under identical conditions using the same test solutions for two test carbons can be quickly and conveniently compared to reveal the relative merits of the carbons. Thus, isotherm data represent a large amount of information condensed into concise form for ready evaluation and interpretation.

The adsorption isotherm data of Robeck et al. (1965) were obtained using powdered carbon and pesticides dissolved in distilled water and river water. The data of Hager and Rizzo (1974) were obtained using granular carbon and pesticide in distilled water. In general, the results of these two studies are in agreement, and show that both powdered and granular carbon are capable of producing endrin concentrations of 0.2 ppb and below.

Pilot-Scale Studies - Although the treatability of a particular wastewater by carbon and the relative capacity of different types of carbon for treatment may be estimated from adsorption isotherms, carbon performance and design criteria are best determined by pilot tests. Pilot carbon column tests are performed for the purpose of obtaining design data for full-scale plant construction. Adsorption isotherms are determined using batch tests, but the actual treatment of wastewater by activated carbon most often is effected in a continuous system involving packed beds similar to filtering operations.

Pilot tests are required in order to provide the required estimates of performance that can be expected in a full-scale unit.

To the best of our knowlege, pilot carbon column tests for the removal of endrin from water have not been performed.

EFFLUENT QUALITY ACHIEVABLE USING ALTERNATE TREATMENT SYSTEMS

Laboratory studies are available from which the quality of effluent achievable from each alternate treatment system can be estimated. An important point to remember is that these data are based only on laboratory studies, and, therefore, the quality of the effluent from a full-scale treatment plant may differ significantly.

The influent to each alternate system is presumed to be saturated with endrin (see discussion of the "Present Treatment System"). Dr. Robert Swank (1975b) has stated that the solubility of endrin is about 300 ppb. However, Marks (Vitalis, 1975) has stated that the solubility of endrin is 200 ppb (in distilled water at 20°C). According to Richardson and Miller (1960), the solubility of endrin is 230 ppb at 25°C, 380 ppb at 35°C and 510 ppb at 45°C.

On the basis of the above experimental data, we have presumed that the influent to the various alternate treatment systems contains about 200 ppb endrin.

Resin Adsorption System

Velsicol (Marks, 1974a) has demonstrated in the laboratory that the XAD-4 resin absorbent system can reduce the concentration of endrin in the wastewater down to an average of 1.36 ppb. Endrin levels of 0.5 to 1.0 ppb were reached on occasion. Recent laboratory studies using 3 in. diameter glass columns have shown that the concentrations of endrin and associated products could be maintained below 1 ppb (Marks, 1975b).

Reductive Degradation System

Envirogenics Systems Company (1973) has demonstrated in the laboratory that the reductive degradation system using copper-catalyzed iron can reduce the concentration of endrin down to 1 ppb, but the results have been erratic depending upon the operating conditions. In several experimental runs, conducted by Envirogenics Systems Company (1974b) for example, the concentration of endrin in the treated effluent exceeded 100 ppb. Recent laboratory studies have indicated that, at a flow rate of 8.5 to 9.7 gpm/ft^2, all pesticide components in the effluent were less than 1 ppb (Marks, 1975b).

We assume here that the reductive degradation system can maintain the concentration of endrin in the treated process wastewater at less than 1 ppb (since this has been achieved in some cases) with the realization that several refinements to the existing process may be necessary to maintain this level of control.

Amberlite XAD-4 Resin System and Reductive Degradation System in Series

In this combined system, the endrin wastewater is treated initially using the resin adsorption process; the effluent is subsequently treated using the reductive degradation process.

The reductive degradation process has been shown to be capable of treating low concentrations of endrin in water; Envirogenics Systems Company (1974b) has demonstrated that the reductive degradation system can reduce a low concentration of endrin in water (30 ppb) down to less than 0.1 ppb (at a pH of 7.0). Thus, it is probable that the two processes acting in series will be capable of reducing the endrin concentration in the wastewater down to about 0.1 ppb.

Carbon Adsorption System

According to the published isotherm data of Hager and Rizzo (1974) and those of Robeck et al. (1965), activated carbon is capable of reducing the concentration of endrin in water to approximately 0.2 and 0.03 ppb, respectively. Robeck et al. (1965) have also shown that greater than 99% endrin removal (at 10 ppb load) can be achieved at a flow rate of 0.5 gpm/ft^3 using a bed of activated carbon. On the basis of the above experimental data, we estimate that the carbon adsorption system which we have examined (see the following section of this report dealing with "Wastewater Treatment Cost Estimates") would reduce the endrin concentration from 200 ppb to less than 2 ppb.

Potential for Zero Discharge

When the planned endrin wastewater treatment system is in operation at Velsicol (Memphis, Tennessee), the potential for zero discharge is reported to be good (Swank, 1975). For example, the treated wastewater discharged from the reductive degradation process could be recycled back into the process for use as cooling water and for use in the gas scrubber system. Thus, for treatment applications in which reductive degradation is used alone or in series with an XAD-4 resin system, there is apparently a significant potential for zero discharge of effluent. However, there appears to be no way to prevent the runoff of surface water (Swank, 1975b).

Comparison of Effluents Produced by Alternate Treatment Systems with Effluent Limitations Guidelines

The Environmental Protection Agency in their "general instructions" to contractors (Part II) describes effluent limitations guidelines in terms of Levels I, II, and III technology. These levels of technology are briefly defined below and replace the terms "best practicable control technology currently available" (BPCTCH), "best available technology economically achievable" (BATEA), and "best available demonstrated control technology."

Level I control and treatment technology must be achieved by all plants in each industry not later than July 1, 1977. "Level I technology should be based upon the average of the best existing performance by plants of various sizes, ages, and unit processes within each industrial category or subcategory. This average shall not be based upon a broad range of plants within an industrial category or subcategory, but shall be leased upon performance levels achieved by exemplary plants."

Level II control and treatment technology is to be achieved not later than July 1, 1983. "Level II technology is not based upon an average of the best performance within an industrial category, but is to be determined by identifying the very best control and treatment technology employed by a specific point source within the industrial category or subcategory, or where it is readily transferable from one industry process to another, such technology may be identified as Level II technology."

Level III control and treatment technology is to be achieved by new sources. "Level III technology shall be evaluated by adding to the consideration underlying the identification of Level II technology a determination of what higher levels of pollution control are available through the use of improved production processes and/or treatment techniques.

Effluent limitations guidelines have been tentatively recommended (Weston, 1975) for the "Halogenated Organic Pesticides" subcategory of the "Pesticides and Agricultural Chemicals Industry" category (Table 2).

All of the alternate treatment systems for the removal of endrin from wastewater require a preliminary sedimentation and filtration step. Thus, the total suspended solids would be reduced to the approximate levels permitted by Level III technology.

Limited data are available concerning the COD, BOD_5 and phenol concentration of the present wastewater but no data of this kind are available for the reduced flows which would be treated in the alternate systems.

Table 2. EFFLUENT LIMITATIONS GUIDELINES FOR HALOGENATED ORGANIC PESTICIDES (Tentative Recommendations)

Level of technology	Effluent characteristic	Effluent limitations: Average of daily values for 30 consecutive days shall not exceed		Effluent limitations: Maximum for any 1 day	
		kg/kkg[a/]	mg/ℓ	kg/kkg	mg/ℓ
Level I (BPCTCA)	BOD_5	1.01		1.80	
	Phenol	0.0015		0.002	
	TSS		84		156
Level II (BATEA)	BOD_5	1.01		1.80	
	Phenol	0.0015		0.0020	
	COD	1.53		2.12	
	TSS		42		78
Level III (BADCT)	BOD_5	1.01		1.80	
	Phenol	0.0015		0.0020	
	TSS		42		78

a/ kg/kkg production is equivalent to lb/1,000 lb production.
Source: Weston (1975).

Thus, it is not possible to make direct comparisons between the quality of the effluent produced by the alternate treatment systems and the quality of the effluent permitted by the effluent limitations guidelines; however, the treatment required to reduce endrin concentrations to 1 ppb and below require more extensive treatment than is required to meet effluent limitations guidelines. The effluent from the sedimentation/filtration steps would probably meet effluent limitations guidelines, even for Level III technology. However, to achieve acceptable levels of endrin concentrations the wastewater stream would require additional treatment as indicated in this report in the description of "Alternate Treatment Systems."

SECTION IV

WASTEWATER TREATMENT COST ESTIMATES

DESCRIPTION OF ALTERNATE TREATMENT SYSTEMS

Conceptual flow diagrams for the four alternate treatment systems are presented in Figures 2 through 5. In each case, the initial steps include sedimentation and filtration. These steps are required in order to remove the suspended solids that would otherwise pass through the adsorption systems or overburden the reductive degradation system. The figures show the quality of the untreated wastewater, the quality of the treated effluent discharged to the municipal sewer, and the sludge disposal operations.

The treatment systems have been cost analyzed on the basis that the discharge waters will be adequately segregated and that the flow rate of the treated wastewater will be 300 gpm. This flow rate represents a significant decrease from the current flow rate which averages 3,514 gpm (Vitalis, 1975; see section of this report entitled "Wastewater Characteristics").

The reduced flow rate (300 gpm) is both desirable and possible, but the possibility exists that the actual flow rate of wastewater requiring treatment may be higher. As the flow rate of the wastewater increases, the physical capacity of the treatment system, and therefore, its cost, must also increase.

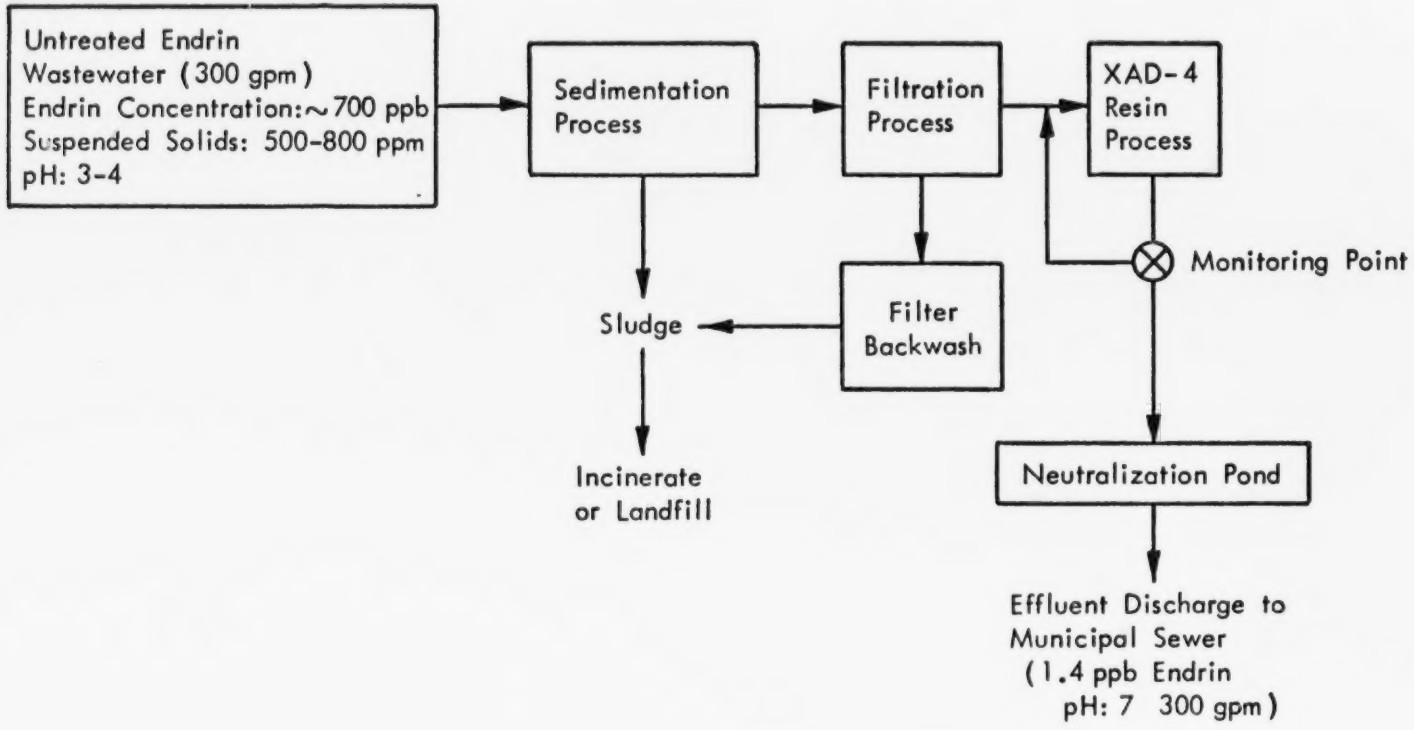


Figure 2. Conceptual flow diagram of a resin adsorption system for the treatment of endrin wastewater.

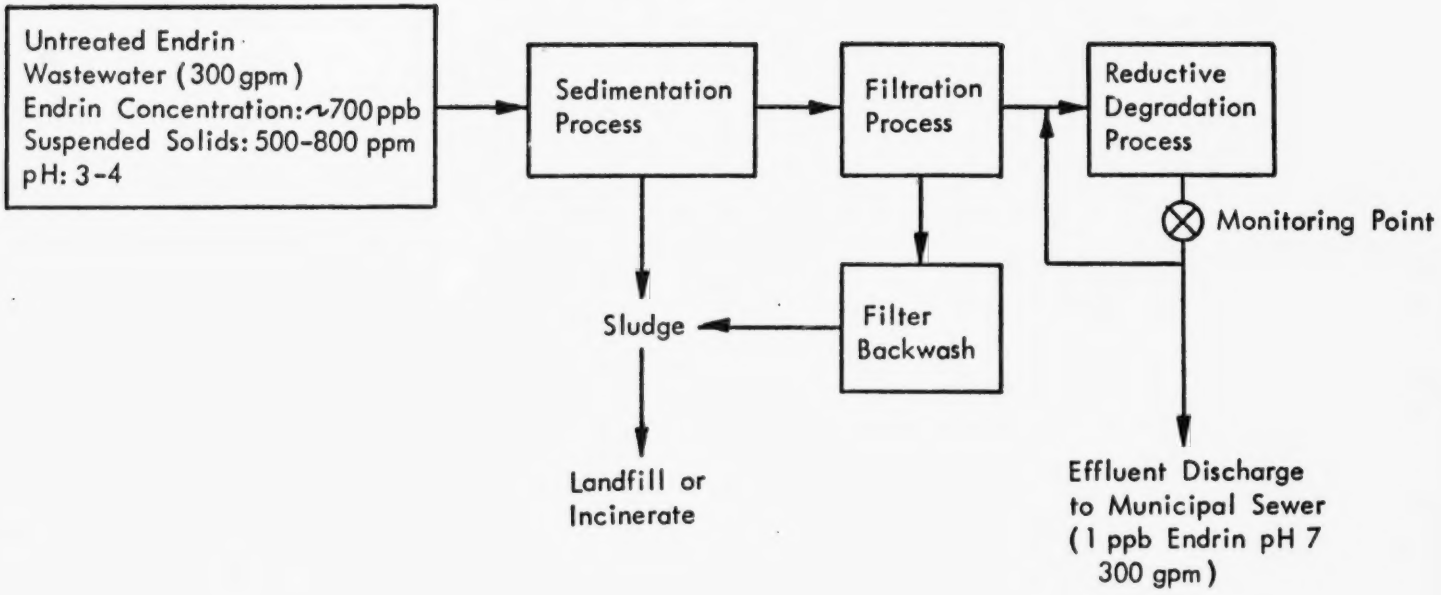


Figure 3. Conceptual flow diagram of a reductive degradation system for the treatment of endrin wastewater.

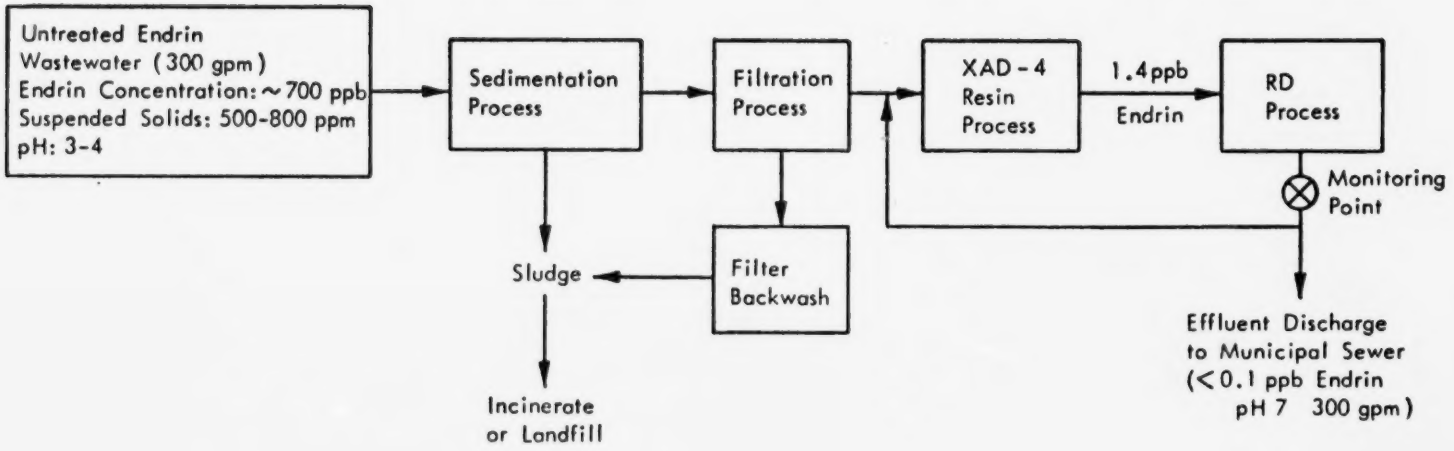


Figure 4. Conceptual flow diagram of a resin adsorption system and a reductive degradation system in series for the treatment of endrin wastewater.

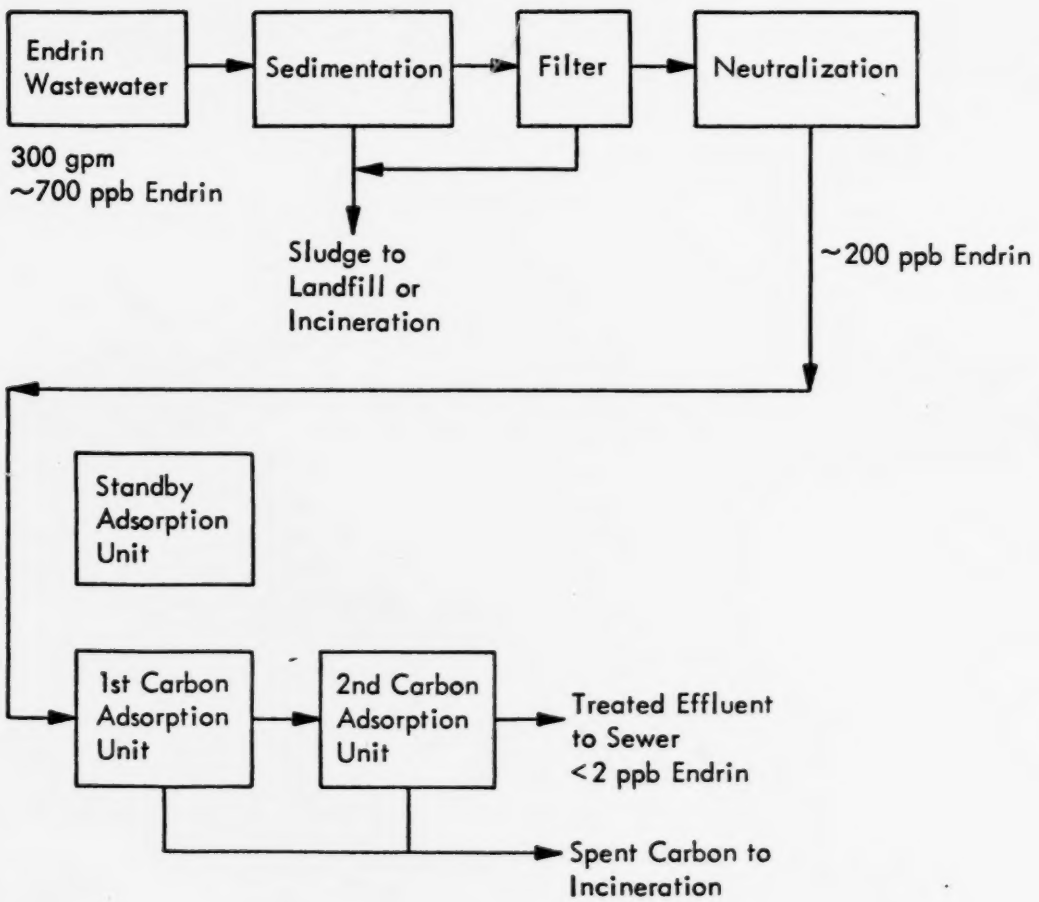


Figure 5. Conceptual flow diagram of an activated carbon adsorption system for the treatment of endrin wastewater.

In each system a neutralization step would be required because of the relatively high acidity of the raw wastewater (pH 3 to 4). The reductive degradation process requires an essentially neutral effluent, but the resin adsorption and carbon processea can operate using an acidic influent. In any case, it would not be legal to discharge the acidic effluent without a neutralization step. Thus, the optimum location of the neutralization step within the system is not known. However, for purposes of cost estimation, it makes little difference at which point neutralization occurs. Therefore, each treatment system, except carbon adsorption, is costed at two different flow rates--300 and 600 gpm. The 600 gpm flow rate was arbitrarily chosen for comparative purposes, and shows how the cost will increase for a given treatment system at twice the anticipated flow rate of 300 gpm.

Figure 2 shows the resin adsorption system. The resin adsorption process operates by passing the wastewater through two vertical columns packed with the resin that adsorbs endrin as it passes through the column. The resin beds are about 7 ft in diameter and 15 ft high (Swank, 1975). Periodically the resin is regenerated by flushing the resin beds with isopropyl alcohol to remove the accumulated endrin. The treated wastewater (pH 3 to 4) is then pumped into a neutralization pond and neutralized (pH 7) with limestone. The treated wastewater is then discharged into the municipal sewer system.

Figure 3 shows the reductive degradation system. The reductive degradation process operates by first neutralizing (pH 7) the acid wastewater (pH 3 to 4) in a pH adjustment tank. After neutralization, the wastewater passes through reductant columns (in parallel) packed with copper-catalyzed iron and sand, and the endrin is destroyed. Subsequently, the treated wastewater is discharged into the municipal sewer system.

Figure 4 shows the two systems in series. The wastewater is processed through the XAD-4 resin system, the reductive degradation system, and then discharged into the municipal sewer system.

A conceptual flow diagram for a carbon adsorption process is shown in Figure 5. The portions of this process which deal with removal of suspended solids and pH adjustment in the raw wastewater are taken to be identical to the process steps of sedimentation, sand filtration and neutralization, which are used in the reductive degradation system. Hager (1974) indicates that suspended solids in amounts exceeding about 50 mg/liter should be removed prior to treatment of effluent in carbon adsorption beds and that pH adjustment can be employed to enhance adsorption efficiency.

Following removal of suspended solids, the wastewater is conducted through a two-stage carbon adsorption system which consists essentially of (a) two on-stream carbon adsorption units operating in series and one stand-by unit packed with granular activated carbon, and (b) the required auxiliary equipment (pumps, piping, process instrumentation, etc.). After treatment, the wastewater is discharged into the municipal sewer.

When the concentration of endrin in the effluent from the first unit is equivalent to the feed concentration, the carbon in the unit is exhausted and the unit is taken off stream. The second unit then becomes the lead unit and the standby column is put on stream as the second column in the series. The exhausted carbon is discharged and the unit is refilled with fresh carbon, and used as standby. Because of the small requirement for activated carbon, regeneration of the carbon is not economically justified. The exhausted carbon would be disposed of by incineration; the costs for incineration are not included in this study. One exhausted carbon unit could be taken off stream about every 30 months.

ESTIMATED CAPITAL INVESTMENT COSTS FOR THE RESIN ADSORPTION SYSTEM AND THE REDUCTIVE DEGRADATION SYSTEM

Information concerning the alternate treatment systems and their associated costs is derived in part from information submitted by Velsicol Chemical Corporation (Marks, 1974b), and in part from reports by Envirogenics Systems Company (1974a, 1974b), concerning the pilot plant demonstration units. If the costs of required process equipment or labor were not stated by the two above companies, these costs are estimated. In addition, the treatment systems are scaled up from the demonstration units (100 gal/min flow) to 300 and 600 gpm, and the costs are given in April 1975 dollars.

Since all of the alternate systems require both a sedimentation and filtration process, and the costs of these two processes are identical for each system, these processes are given first. Following the treatment and filtration processes, each of the alternate systems is discussed separately. The cost estimates for the systems are then summarized and totaled.

Sedimentation Process Costs

The sedimentation process will allow large solid undissolved particles to settle out of the wastewater prior to filtration. The installed capital cost for a system to handle 300 gpm (432,000 gpd) and 600 gpm (864,000 gpd) is estimated from a report by Blecker and Nichols (1973). The graph on page 126 of their report shows that the installed cost (1972 dollars) of a sedimentation system to handle 1 million gallons per day is $65,000. The installed costs for the systems to handle 300 and 600 gpm flows are extrapolated from the graph and are $25,000 and $45,000, respectively. These installed systems for the sedimentation process include the purchased cost of tanks, motors and drives, pumps, piping, concrete, structural steel, instrumentation, electrical, paint, and indirect costs.

Since these installed costs are given in 1972 dollars, the costs must be escalated to April 1975 prices. To do this, the Chemical Engineering (CE) Plant Cost Index is used. Chemical Engineering (1975a) reports that in 1972, this index was 137.2 but had risen to 180.6 by April 1975. Therefore, the estimated installed capital cost (rounded) of each sedimentation process system is:

300 gal/min process: ($25,000) $\left(\frac{180.6}{137.2}\right)$ = ~ $33,000

600 gal/min process: ($45,000) $\left(\frac{180.6}{137.2}\right)$ = ~ $59,000

Blecker and Nichols (1973) reported that the annual maintenance cost for each process is about 15% of the installed cost or $5,000 and $8,900, respectively. This report also states that the process requires no operator attention. However, operating labor is estimated at 3 hr/day for routine checks on the process to see that it functions properly.

Periodically the sludge must be removed and landfilled or incinerated. The cost of sludge removal is included in the maintenance cost. The cost of land for landfill or the cost of incineration of the sludge is excluded in this estimate.

Blecker and Nichols (1973) report the expected life of these systems is between 25 and 60 years, and is taken to be 40 years for the purpose of depreciation of the installed costs (see Appendix A).

Filtration Process Costs

The wastewater is pumped from the sedimentation process (at the same rate as the inflow) into a sand filter to further remove suspended solids. The flow rate through a sand filter can vary depending upon the design, but a typical flow rate, according to Envirogenics Systems Company (1973), is about 3.2 gal/ft^2/min. Thus, the required filter area for the 300 and 600 gal/min flows is about 100 and 200 ft^2, respectively. A back-up filter is required for each process since the plant operates 24 hr/day.

The installed cost for the filtration process is obtained from the report by Blecker and Nichols (1973). The graph on page 66 of this report shows that the installed cost of a 100 ft^2 filter is \$60,000 and a 200 ft^2 filter is \$80,000. Since these costs are in 1972 dollars, the April 1975 costs (rounded) are:

300 gal/min filtration process: $(2)(\$60{,}000)\left(\frac{180.6}{137.2}\right) = \sim \$158{,}000$

600 gal/min filtration process: $(2)(\$80{,}000)\left(\frac{180.6}{137.2}\right) = \sim \$210{,}000$

Blecker and Nichols (1973) reported that the annual maintenance cost for each process is about 5% of the installed cost, or \$7,900 and \$10,500, respectively. This report states that the filtration process requires no operator attention. However, operating labor is estimated at 3 hr/day for routine checks on the process to see that it functions properly.

Periodically the filters are backwashed into a sump to remove the filtered solids. Removal of the sludge from the sump is included in the maintenance costs given above. The costs of land for landfill or the cost of incineration of the sludge is excluded in this estimate.

Blecker and Nichols (1973) reported that the expected life of the filtration process is between 11 and 20 years, and is taken to be 15 years for the purpose of depreciation of the installed costs (see Appendix A).

Resin Adsorption System Costs

Velsicol Chemical Corporation designed a system and estimated the costs for an Amberlite XAD-4 resin process to treat 100 gal/min of wastewater. A system is described and the costs are estimated in their R&D grant application submitted to EPA to conduct a project entitled, "Chlorinated Hydrocarbon Pesticide Removal From Wastewater." In another document written by Marks (1974b), the installed capital equipment costs (1973 dollars) were estimated by Velsicol to be $60,000 (excluding the filtration process) for purchased parts and $27,600 for installation of the process, or a total of $87,600. These costs were itemized by Velsicol as follows:

Purchased Parts

2 Resin columns with headers	$16,000	
2 Solvent tanks	22,000	
3 Transfer pumps	6,000	
Instrumentation	4,000	
Valves and piping	4,800	
Contingency on purchased parts	7,200	
	$60,000	$60,000

Subcontracts

Mechanical and electrical construction	$22,000	
Slab and related civil works	5,600	
	$27,600	$27,600
Total cost		$87,600

Chemical Engineering (1975a) shows that the 1973 CE Plant Cost Index was 144.1 so that the April 1975 estimated cost of the XAD-4 resin process is:

$$(\$87,600)\left(\frac{180.6}{144.1}\right) = \sim \$110,000$$

This cost is for a 100 gal/min flow rate and must be scaled up to 300 and 600 gal/min, respectively. Since this process involves tanks, pumps, piping, and resin columns, the best available method to scale up this plant is the logarithmic relationship known as the "six-tenths factor" (see Appendix A).

Using this method, the installed cost for the XAD-4 resin process is:

300 gal/min process: $(\$110,000)\left(\frac{300}{100}\right)^{0.6} = \sim \$212,000$

600 gal/min process: $(\$110,000)\left(\frac{600}{100}\right)^{0.6} = \sim \$322,000$

These costs do not include the cost of neutralizing the treated wastewater prior to discharging it into the municipal sewer system. Since the current practice at Velsicol (Vitalis, 1975) is to pump the endrin wastewater into a large lagoon and neutralize the wastewater with lime prior to discharge, the only cost added by the XAD-4 resin system is the cost of the lime since the lagoon already exists.

The cost of the lime is negligible in this treatment system compared to the cost of the resin and isopropyl alcohol (discussed subsequently) since the amount of lime required to neutralize the wastewater (from pH 3 to 7) is about the same as the amount of sodium carbonate required in the reductive degradation system (Cywin and Martin, 1973), which amounts to

44,100 lb/year for a 100 gal/min plant and the cost of lime is only 1/10 the cost of sodium carbonate, or about $10/ton. On an annual basis this amounts to a cost of $220 to neutralize the wastewater of a 100 gal/min plant. For the 300 and 600 gal/min plant the costs would be $660 and $1,320, respectively, which are negligible in this case.

The material costs are essentially the Amberlite XAD-4 resin and the isopropyl alcohol used to regenerate the contaminated resin columns. Velsicol (Vitalis, 1975) estimates that the cost of the resin to charge the resin columns for the 100 gal/min system is $63,000 (current prices), and that the resin has an operating lifetime of 5 years. Rohm and Haas Company (Kennedy, 1973) estimates that the cost of the regeneration isopropyl alcohol makeup is $30,000/year (1972 prices) for a 100 gal/min process. The average 1972 price of isopropyl alcohol was about $0.45/gal (Oil, Paint and Drug, 1972) and is currently $0.70/gal, (Chemical Marketing Reporter, 1975) so that the isopropyl alcohol cost in April 1975 prices is (0.70/0.45) ($30,000) or $46,700/year for a 100 gal/min plant.

Using a linear relationship to scale up the resin and isopropyl alcohol required for the two process flow rates gives:

Resin:

300 gal/min process: $\$63{,}000 \left(\frac{300}{100}\right) = \sim \$189{,}000$

600 gal/min process: $\$63{,}000 \left(\frac{600}{100}\right) = \sim \$378{,}000$

Isopropyl Alcohol:

300 gal/min process: $(\$46{,}700/\text{year}) \left(\frac{300}{100}\right) = \sim \$140{,}100/\text{year}$

600 gal/min process: $(\$46{,}700/\text{year}) \left(\frac{600}{100}\right) = \sim \$280{,}200/\text{year}$

Blecker and Nichols (1973) reported that the annual maintenance cost for each process is about 5% of the installed equipment cost, or $10,600 and $16,100, respectively.

The operating labor time is estimated at 9 man-hours/day on a 24 hr/day operating basis for the 100 gal/min system based upon the estimates given for ion exchangers (Blecker and Nichols, 1973). This gives a requirement of 3,150 man-hours annually (based on 350 operating days per year). To scale this labor time up to the 300 and 600 gal/min process flow rates, the "one-fourth factor" (Modern Cost-Engineering Techniques, 1970) is used (see Appendix A). This method gives the estimated operating labor time for each process as follows:

$$\text{300 gal/min process operating labor: } (3{,}150 \text{ hr}) \left(\frac{300}{100}\right)^{0.25} = 4{,}150 \text{ hr}$$

$$\text{600 gal/min process operating labor: } (3{,}150 \text{ hr}) \left(\frac{600}{100}\right)^{0.25} = 4{,}900 \text{ hr}$$

Rohm and Haas Company (Kennedy, 1973) estimates that the expected life of the XAD-4 resin process is 10 years, and that the life of the XAD-4 resin charge is 5 years for the purpose of depreciation of the installed costs of the capital equipment and resin.

Reductive Degradation System

Envirogenics Systems Company (1973) designed a pilot plant demonstration system and estimated the cost of a reductive degradation process to remove the endrin from wastewater flowing at 100 gal/min. The system is fully described in the Envirogenic Report (1973) and the associated costs (1973 dollars) are given in detail.

In this document the installed capital equipment costs were estimated by Envirogenics Systems Company to be $58,900. These costs were itemized as follow:

Purchased Parts

2 Reagent mix tanks, 200 gal. with mixers, low-level alarm and proportional feed pump	$ 3,000	
1 Transfer pump with low-level alarm	1,000	
1 pH adjustment tank, approximately 2,000 gal.	2,000	
1 Mixer and impeller, 2 hp	3,000	
1 Low and high level alarm for above	500	
1 5 hp feed pump	700	
1 pH sensing and control unit	2,000	
5 Rotameters	900	
Valves and piping	1,810	
5 Reactor columns with distributors	10,000	
Reagents	190	
Contingency on purchased parts	5,000	
	$30,100	$30,100

Subcontracts

Mechanical and electrical construction	$20,000	
Slab and related civil works	4,000	
Contingency on subcontracts	4,800	
	$28,800	$28,800
Total cost		$58,900

The 1973 Chemical Engineering Plant Cost Index was 144.1 (Chemical Engineering, 1975a) so that the April 1975 cost of the reductive degradation process is:

$$(\$58,900)\left(\frac{180.6}{144.1}\right) = \$73,800$$

This cost is for a 100 gal/min process and must be scaled up to 300 and 600 gal/min, respectively. Since the process involves tanks, pumps, reactor columns, and miscellaneous equipment, the best available method for scaleup is the logarithmic relationship known as the "six-tenths factor," previously described. Using this method, the installed cost for the reduction degradation process is:

$$\text{300 gal/min process: } \$73{,}800 \left(\frac{300}{100}\right)^{0.6} = \$142{,}000$$

$$\text{600 gal/min process: } \$73{,}800 \left(\frac{600}{100}\right)^{0.6} = \$216{,}000$$

The material costs for the system are the replacement of the iron reductant, the copper catalyst, and the sodium carbonate consumed in the process operation. Envirogenics Systems Company (1973) determined that the losses of iron reductant for processing existing endrin wastewater were 5.0 mg/liter of effluent, and losses of copper catalyst were 0.1 mg/liter of effluent. The amount of sodium carbonate required to adjust the pH of the wastewater to 7.0 was determined to be 126 lb/day for the 100 gal/min plant. (Note: Sodium carbonate was used by Envirogenics and is used in this estimate, though its cost is higher than, say, lime. Since it is not known whether or not lime can be used as a neutralizing agent in this process, the savings realized from using the cheaper lime cannot be determined. The difference in price of the two neutralizing agents would not greatly affect the overall process cost.)

iron reductant: $\left(\frac{5.0 \text{ mg Fe}}{\ell}\right)\left(100 \frac{\text{gal}}{\text{min}}\right)\left(3.85 \frac{\ell}{\text{gal.}}\right)\left(1{,}440 \frac{\text{min}}{\text{day}}\right)\left(2.2 \times 10^{-6} \frac{\text{lb}}{\text{mg}}\right)\left(350 \frac{\text{day}}{\text{year}}\right) =$

$2{,}130 \frac{\text{lb}}{\text{year}}$

copper catalyst: $\left(\frac{0.1 \text{ mg Cu}}{\ell}\right)\left(\frac{100 \text{ gal}}{\text{min}}\right)\left(3.85 \frac{\ell}{\text{gal.}}\right)\left(1{,}440 \frac{\text{min}}{\text{day}}\right)\left(2.2 \times 10^{-6} \frac{\text{lb}}{\text{mg}}\right)\left(350 \frac{\text{day}}{\text{year}}\right) =$

$45 \frac{\text{lb}}{\text{year}}$

sodium carbonate: $\left(126 \frac{\text{lb}}{\text{day}}\right)\left(350 \frac{\text{days}}{\text{year}}\right) = 44{,}100 \frac{\text{lb}}{\text{year}}$

The costs of replacing the iron reductant and copper catalyst are negligible since iron powder costs \$0.20/lb and copper sulfate costs \$0.70/lb (Chemical Marketing Reporter, 1975) and the quantities are quite small. The sodium carbonate cost, however, is substantial since its current price is about \$100/ton (Chemical Marketing Reporter, 1975) and a large quantity is required. The sodium carbonate needed for the 300 and 600 gal/min processes is proportional to the flow rate so that the annual cost of sodium carbonate for the two plants is:

300 gal/min plant: $\left(44{,}100 \frac{\text{lb}}{\text{year}}\right)\left(\frac{300}{100}\right)\left(\frac{\$0.05}{\text{lb}}\right) = \$6{,}600/\text{year}$

600 gal/min plant: $\left(44{,}100 \frac{\text{lb}}{\text{year}}\right)\left(\frac{600}{100}\right)\left(\frac{\$0.05}{\text{lb}}\right) = \$13{,}200/\text{year}$

Blecker and Nichols (1973) reported that the annual maintenance costs are 5% of the installed capital equipment costs or \$7,100 and \$10,800 for the 300 and 600 gal/min processes, respectively.

The operating labor time is estimated at 9 man-hours/day on a 24 hr/day operating basis. This gives a requirement of 3,150 man-hours annually (based)

on 350 operating days per year). Scaling this labor time up to the 300 and 600 gal/min processes is accomplished with the "one-fourth factor," previously mentioned, and the annual operating labor time for each process becomes:

$$\text{300 gal/min process operating labor: } (3{,}150 \text{ hr}) \left(\frac{300}{100}\right)^{0.25} = 4{,}150 \text{ hr}$$

$$\text{600 gal/min process operating labor: } (3{,}150 \text{ hr}) \left(\frac{600}{100}\right)^{0.25} = 4{,}900 \text{ hr}$$

The expected life of the reductive degradation process equipment is taken to be 10 years for the purpose of depreciation of the installed equipment costs (see Appendix A).

The Resin Adsorption System and Reductive Degradation System in Series

The cost of a system which puts the XAD-4 resin system and reductive degradation system in series is the same as the sum of the costs for each separate system with only one exception: only one sedimentation and one filtration process is necessary for the two systems in series; that is, each system does not have a separate sedimentation and filtration process. Therefore, the cost of the two systems in series is the sum of the cost of the two separate systems less the cost of one sedimentation process and one filtration process. (A small additional cost is involved when adding valves, piping, etc., to put the systems in series, but it is negligible.)

The fact that the endrin content of the wastewater treated by the reductive degradation system is lower (since the wastewater has already been treated by the XAD-4 resin system) does not reduce the cost of the reductive degradation system in series to any extent for two reasons: (a) the amount

of wastewater treated is the same for the reductive degradation system whether alone or in series with the XAD-4 resin system, and the reductive degradation system must be of approximately the same size in both cases; and (b) the loss of iron reductant and copper catalyst will be lower for the reductive degradation system in series, but the cost of operating the system in series is unaffected since the cost of replacing these materials is negligible.

Total Capital Investment Costs for The Resin Adsorption System and The Reductive Degradation System

The cost of purchasing and installing the capital equipment for each system has been presented in the previous discussions. In addition to the previous cost estimates, a contingency of 30% is added to these costs to allow for unanticipated expenses. Table 3 summarizes and totals the capital investment for the three systems.

ANNUAL OPERATING COSTS FOR THE RESIN ADSORPTION SYSTEM AND THE REDUCTIVE DEGRADATION SYSTEM

The total annual costs to operate each system at both the 300 and 600 gal/min flow rates are estimated below. Most of these costs are a percentage of either the installed capital equipment cost or the labor costs previously described. The following list shows all of the cost items considered in this estimate.

Direct costs

Materials
Labor
Supervision
Payroll charges
Maintenance

Table 3. INSTALLED CAPITAL EQUIPMENT COST FOR THE RESIN ADSORPTION SYSTEM, THE REDUCTIVE DEGRADATION SYSTEM, AND THE TWO SYSTEMS IN SERIES

	Capital investment cost ($)					
	Resin system		Reductive degradation system		The two systems in series	
Process	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Sedimentation	33,000	59,000	33,000	59,000	33,000	59,000
Filtration	158,000	210,000	158,000	210,000	158,000	210,000
Resin adsorption process						
Equipment	212,000	322,000	-	-	212,000	322,000
Resin	189,000	378,000	-	-	189,000	378,000
Reductive degradation process	-	-	142,000	216,000	142,000	216,000
Subtotal	592,000	969,000	333,000	485,000	734,000	1,185,000
Contingency, 30%	178,000	291,000	100,000	146,000	220,000	356,000
Total (1975 $)	770,000	1,260,000	433,000	631,000	954,000	1,541,000

Operating supplies
Utilities
Laboratory services

Indirect costs

Depreciation
Property taxes
Insurance
Capital cost
Plant overhead

Materials

The only material cost of any consequence is the sodium carbonate used to neutralize the wastewater and the isopropyl alcohol used to regenerate the resin. (The Amberlite XAD-4 has a 5 year useful life and is depreciated with the capital equipment.) These costs have been previously given.

Labor

Labor costs are wages paid to operating labor. The total annual labor required for the three systems (based on 350 operating days per year) is:

	Annual man-hours					
	XAD-4 resin system		RD system		Two systems in series	
Process	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Sedimentation	1,050	1,050	1,050	1,050	1,050	1,050
Filtration	1,050	1,050	1,050	1,050	1,050	1,050
XAD-4 Resin Process	4,150	4,900	-	-	4,150	4,900
RD Process	-	-	4,150	4,900	4,150	4,900
Total	6,250	7,000	6,250	7,000	10,400	11,900

The hourly earnings of production or nonsupervisory workers in the chemical and allied products industry was $5.18/hr in March 1975 (Monthly Labor Review, 1975). For April 1975, the estimated wage rate is $5.20/hr. This gives an annual operating labor cost for each of the systems as follows:

System	Flow rate (gal/min)	Annual man-hours	Hourly wage	Annual operating labor cost
XAD-4 Resin	300	6,250	$5.20	$32,500
	600	7,000	5.20	36,400
Reductive Degradation	300	6,250	5.20	32,500
	600	7,000	5.20	36,400
Two Systems in Series	300	10,400	5.20	54,100
	600	11,900	5.20	61,900

Supervision

Supervision of labor is normally estimated as a percentage of operating labor, a typical value being 20% (Jelen, 1970). Using this typical value of 20% of operating labor costs for labor supervision costs gives the following estimates:

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Annual Labor Supervision Cost	$6,500	$7,300	$6,500	$7,300	$10,800	$12,400

Payroll Charges

These costs are the result of the many fringe benefits employees receive in addition to their salaries. Recent emphasis on these benefits in labor

contracts make this cost substantial and it is steadily increasing with time. According to Perry and Chilton (1973) the sum of fringe benefits may add between 15 and 40% to the wage rate of employees, and this varies widely from company to company. In this estimate, payroll charges (fringe benefits) are taken to be 30% of the wages paid to both labor and supervision. These payroll charges are thus estimated to be:

System	Flow rate (gal/min)	Total operating labor and supervision cost	Payroll charge
XAD-4 Resin	300	$39,000	$11,700
	600	43,700	13,100
Reductive Degradation	300	39,000	11,700
	600	43,700	13,100
Two Systems in Series	300	64,900	19,500
	600	74,300	22,300

Maintenance

Maintenance costs have been determined previously for each process. They are summarized below to give the total annual maintenance costs for each system.

	Annual maintenance cost ($)					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
Process	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Sedimentation	5,000	8,900	5,000	8,900	5,000	8,900
Filtration	7,900	10,500	7,900	10,500	7,900	10,500
XAD-4 Resin Process	10,600	16,100	-	-	10,600	16,100
RD Process	-	-	7,100	10,800	7,100	10,800
Total	23,500	35,500	20,000	30,200	30,600	46,300

Operating Supplies

Operating supplies are items such as lubricating oil, instrument charts, etc., that are neither raw nor repair materials. The cost of these items is typically 6% of labor costs (Jelen, 1970). This amounts to an annual cost for operating supplies of:

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Annual Operating Supplies Cost	$2,000	$2,200	$2,000	$2,200	$3,200	$3,700

Utilities

The utilities required for the processes are primarily electrical power. Little water is required if we assume that processed wastewater is recycled to the filter backwash and sodium carbonate mixing tanks. The estimated annual electrical cost for the 100 gal/min reductive degradation system is $1,350; (Envirogenics Systems Company, December 1973) for the XAD-4 resin system is $650 (Marks, 1974b) and for pumping 100 gal/min of wastewater in the sedimentation and filtration process is $100.

These costs are scaled up by direct proportion to give an annual electrical cost to each system as follows:

Process	Annual electrical costs ($)					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Sedimentation and Filtration	300	600	300	600	300	600
XAD-4 Resin Process	2,000	3,900	-	-	2,000	3,900
RD Process	-	-	4,100	8,100	4,100	8,100
Total	2,300	4,500	4,400	8,700	6,400	12,600

Laboratory Services

Laboratory services furnished to support the treatment processes and monitoring operations are estimated at 20% of labor costs (Jelen, 1970). The annual laboratory services cost for the systems, therefore, are:

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Annual Laboratory Service Cost	$6,500	$7,300	$6,500	$7,300	$10,800	$12,400

Depreciation

Depreciation is a periodic charge that distributes the installed capital investment cost over its expected service life. This cost estimate uses straight line depreciation and assumes all capital assets have a zero salvage value. The capital investment costs and expected lives of all depreciable assets have been previously given and are used below to determine the annual depreciation cost for the three systems (rounded to nearest $100).

Capital Asset	Life (year)	Annual depreciation cost ($)					
		XAD-4 resin system		Reductive degradation system		Two systems in series	
		300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Sedimentation Process	40	1,100	1,900	1,100	1,900	1,100	1,900
Filtration Process	15	13,700	18,200	13,700	18,200	13,700	18,200
XAD-4 Resin Process	10	27,600	41,900	-	-	27,600	41,900
XAD-4 Resin Charge	5	49,100	98,300	-	-	49,100	98,300
RD Process	10	-	-	18,500	28,100	18,500	28,100
Total		91,500	160,300	33,300	48,200	110,000	188,400

Property Taxes, Insurance, and Capital Costs

Property taxes, insurance and capital costs are estimated as a percentage of the installed capital equipment cost. These costs are calculated and reported in this report separately to show the cost breakdown of these three items.

Jelen (1970) reports that property taxes are taken to be 2% of investment cost and insurance is generally about 1% of investment cost. Capital cost (or interest) is a charge to finance the investment expenditures. This interest may be a real cost when funds are borrowed to finance the investment, or an assumed cost when internal funds are used (since internal funds would earn interest if loaned out rather than purchased capital assets). The annual rate of interest has varied widely in the recent past and is taken to be 10% for 10 years due to current market interest rates and current cost literature (Chemical Engineering, 1975b). As shown in the Appendix, this is equivalent to an annual interest rate of 6.3% of capital investment.

Using the above percentages gives the following indirect costs for the three systems:

Cost Item	Annual cost ($)					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Property Taxes (2%)	11,800	19,400	6,700	9,700	14,700	23,700
Insurance (1%)	5,900	9,700	3,300	4,900	7,300	11,900
Capital Cost (6.3%)	59,200	96,900	33,300	48,500	73,400	118,500

Plant Overhead

Plant overhead is a charge to the costs of the manufacturing facility which are not chargeable to any particular operation and are normally charged on an allotted basis. Overhead includes such cost items as plant supervision, plant guards, janitors, cafeterias, administrative offices, accounting, purchasing, etc. Overhead costs will vary from company to company and are usually calculated as a percentage of direct labor cost or a percentage of installed capital investment for the entire facility, and allocated to each operation based on its labor or investment cost.

Jelen (1970) reports that plant overhead can range from 40 to 60% of direct labor costs or 15 to 30% of direct costs. We estimate that plant overhead is 20% of direct costs in this report.

TOTAL COST ESTIMATES FOR THE RESIN ADSORPTION SYSTEM AND THE REDUCTIVE DEGRADATION SYSTEM

The total costs of the resin adsorption system, the reductive degradation system and the two systems in series are given in Table 4. The table shows that the total installed capital equipment costs for the three systems are: (a) XAD-4 resin system, $770,000 (300 gal/min) and $1,260,000 (600 gal/min); (b) reductive degradation system, $433,000 (300 gal/min) and $631,000 (600 gal/min); and (c) the two systems in series, $954,000 (300 gal/min) and $1,541,000 (600 gal/min). The estimated total annual operating costs are: (a) $433,200 and $741,300; (b) $181,800 and $249,000; and (c) $537,200 and $889,700, respectively. The estimated cost (per 1,000 gal. of effluent) of treating the endrin wastewater effluent is: (a) $2.87 and $2.45; (b) $1.20 and $0.82; and (c) $3.55 and $2.94, respectively. The estimated unit operating costs to treat endrin wastewater per pound of endrin product (based upon 6 million pounds of annual production) are: (a) 7.2 and 12.4¢; (b) 3.0 and 4.2¢; and (c) 9.0 and 14.8¢, respectively. The current sale price for endrin is reported to be $3.00/lb (Bell, 1975).

CARBON ADSORPTION PROCESS COSTS

As indicated in Figure 5, the endrin process wastewater will require (a) sedimentation, (b) filtration, and (c) neutralization prior to adsorption on carbon. The costs of sedimentation and filtration have been discussed earlier in this report, and the costs of the neutralization were discussed in the portion of this report dealing with the costs of the reductive degradation process.

Table 4. TOTAL INVESTMENT COST AND ANNUAL OPERATING COST FOR THREE ENDRIN WASTEWATER TREATMENT SYSTEMS TREATING EITHER 300 OR 600 GAL/MIN WASTEWATER EFFLUENT

Cost item	Cost (1975 $)					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
	300 gal/min	600 gal/min	300 gal/min	600 gal/min	300 gal/min	600 gal/min
Total installed capital equipment cost	770,000	1,260,000	433,000	631,000	954,000	1,541,000
Annual operating costs						
Direct costs						
Materials	140,100	280,200	6,600	13,200	146,700	293,400
Labor	32,500	36,400	32,500	36,400	54,100	61,900
Supervision	6,500	7,300	6,500	7,300	10,800	12,400
Payroll charges	11,700	13,100	11,700	13,100	19,500	22,300
Maintenance	23,500	35,500	20,000	30,200	30,600	46,300
Operating supplies	2,000	2,200	2,000	2,200	3,200	3,700
Utilities	2,300	4,500	4,400	8,700	6,400	12,600
Laboratory	6,500	7,300	6,500	7,300	10,800	12,400
Subtotal	225,100	386,500	90,200	118,400	282,100	465,000
Indirect costs						
Depreciation	91,500	160,300	33,300	48,200	110,000	188,400
Property taxes	15,400	25,200	8,700	12,600	19,100	30,800
Insurance	7,700	12,600	4,300	6,300	9,500	15,400
Capital cost	48,500	79,400	27,300	39,800	60,100	97,100
Plant overhead	45,000	77,300	18,000	23,700	56,400	93,000
Subtotal	208,100	354,800	91,600	130,600	255,100	424,700
Total annual operating costs	433,200	741,300	181,800	249,000	537,200	889,700
Unit operating costs						
Cost $/1,000 gal. effluent	2.87	2.45	1.20	0.82	3.55	2.94
Cost $/lb of endrin produced (6 million pound produced in 1975)	0.072	0.124	0.030	0.042	0.090	0.148

The capital equipment costs of the carbon adsorption unit in the system are estimated below at two contact times. Following this are the cost summaries for the entire system which includes sedimentation, filtration, neutralization and carbon adsorption.

The cost of a carbon adsorption process to treat 300 gpm of endrin contaminated wastewater at Velsicol's Memphis Plant is estimated from cost information obtained from two sources. The first source is Mr. Roy H. Hutchins, Development Associate, Product Development Department, ICI United States, Inc., Wilmington, Delaware (Hutchins, 1975a). The second source is a process design manual for carbon adsorption (Cornell, 1973).

The treatability of a particular wastewater by activated carbon and the relative capacity of carbon for treatment can be estimated from adsorption isotherm data, obtained by batch testing. However, carbon performance and design criteria are best determined by pilot tests under dynamic flow conditions. The required contact time for a given carbon adsorber column (i.e., the residence time required for the wastewater in a carbon column) is an important design consideration for carbon adsorption systems. The contact time data can only be accurately determined by pilot tests which simulate full-scale operating conditions. Unfortunately, contact time data of this type are not available. Therefore, two different assumed values of contact time were used in this study as a means for estimating a range of investment and operating costs. The two contact times considered were:

1. 30 min contact time (15 min retention in each of two carbon columns in series). This retention time was shown to be effective for endrin by data reported by Robeck (1965) (Table 13; p. 198).

2. 60 min contact time (30 min retention in each of two carbon columns in series).

Capital Investment Costs for Carbon Adsorption Unit With 30 Min Contact Time

Carbon adsorption isotherm data reported by Robeck (1965) for tests with endrin contaminated river water were used to estimate the endrin removal which could be accomplished per unit of granular activated carbon used in the conceptual wastewater treatment system. As recommended by Hutchins (1975a) the river water isotherm for Figure 6-e of Robeck (1965) was extrapolated to determine the endrin removal per unit of carbon corresponding to an endrin concentration of 200 ppb--the endrin concentration in wastewaters to be treated by carbon adsorption. The value obtained by extrapolation is 100 µg of endrin per microgram of carbon; this corresponds to a 10% loading on the carbon (e.g., 10 lb of carbon adsorbs 1 lb of endrin).

The total quantity of endrin to be removed per day (reduction from 200 ppb to 1 ppb of endrin in wastewater) by the conceptual adsorption systems is calculated as follows:

300 gpm x 3.785 liters/gal x 200 µg/liter = 227,000 µg/min of endrin-entering

300 gpm x 3.785 liters/gal x 1 µg/liter = 1,130 µg/min of endrin-leaving system

Difference = ~ 226,000 µg/min of endrin retained on carbon

The estimated carbon requirement for 10% pickup is 226,000 x 10 or 2,260,000 µg/min or 2.26 g/min or 2.26 x 60 x 24 = 3,254 g/day or $\frac{3,254}{453.6}$ = 7.2 lb/day.

Hutchins (1975b) has stated that the efficient use of carbon in the adsorption system can be maximized by a counter-current type of operation as depicted in Figure 5. In this conceptual process, two adsorber columns are operated in series continuously, while a third adsorber unit is always held on standby. All three columns would have the same physical size and initial fresh carbon charge. When break-through occurs in the first absorber (i.e., the total charge becomes fully spent) the unit is taken out of service. The second column then becomes the lead column (No. 1), and the standby adsorber is then placed in service as the second adsorber. The original No. 1 adsorber column is then discharged, the spent carbon disposed of as solid waste to be incinerated and the drained wastewater is reprocessed through the system; the column is then recharged with fresh carbon and held on standby for a subsequent repetition of the operation described above. In this arrangement there is no regeneration of spent carbon. According to Hutchins (1975b) it would be more economical to discard the used carbon because of the low carbon usage rate. Hutchins (1975a) has estimated that one carbon unit ($\sim$ 12,000 lb of carbon) would become spent about every 30 months.

On the basis of data provided by Robeck (1965) and Cornell (1973) and at the recommendation of Hutchins (1975a) it was considered that the two on-stream adsorbers would have a total wastewater to carbon contact time of 30 min (i.e., 15 min contact in each of two adsorbers) and that the flow rate through the carbon bed would be 4 gpm/ft^2 of adsorber bed cross-sectional area.

At 300 gpm, a 15 min contact time corresponds to a holding volume per vessel of 300 x 15 or 4,500 gal. or 602 ft^3. Cornell (1973) recommends 50% additional adsorber volume to provide for backwash operations. Thus, the total volume of each vessel would be 1.5 x 4,500 or 6,750 gal. or 903 ft^3. Hutchins (1975) has suggested a flow rate of 4 gpm/ft^2 through the carbon contactors. On this basis, the size of each contactor would be approximately 10 ft dia ($\frac{300}{4}$ = 75 ft^2 cross-sectional area) by about 11 ft high. Hutchins (1975) has recommended an initial charge of 12,000 lb carbon* per vessel. Considering downflow operation of the contactors, the effective volume (carbon volume) in each adsorber (contactor) would be $\frac{12,000\ lb}{23\ lb/ft^3}$ = 522 ft^3 (approximately a 7 ft bed depth of carbon).

Cost for Carbon Contactor Units - Cost data reported by Cornell (1973) (Figure 5-1, p. 5-4) were used to estimate the installed cost for three equal-sized carbon adsorber columns (contactors). Cornell's Figure 5 relates the construction cost to effective contactor volume. Since the volume of the contactors considered in this study (522 ft^3) is off-scale on the low side in this figure, the 0.6 power factor relationship was used to estimate the contactor cost. A contactor with an effective volume of 1,000 ft^3 has a construction cost of $80,000 (Figure 5-1, Cornell, 1973). By the 0.6 factor relationship (see Appendix A):

$$\$80,000 = \left(\frac{1,000}{522}\right)^{0.6} C \qquad C = \$54,200/\text{contactor}$$

Then, the cost for three contactors would be 3 x $54,200 or $162,600. Updating this cost for inflationary changes using Marshall and Swift cost

* Hydrodarco 4,000 sold by ICI, United States, Inc.

indices for 1975 and 1973 gives:

$$\frac{443.8}{344.1} \times \$162,600 = \$209,800$$

Cost For Influent Pumps Station - As shown in the Cornell (1973) cost data (Figure 5-5, p. 5-11) the cost for an influent pump station for a 300 gpm or 0.43×10^3 gpd is about $10,000. Updating by Marshall and Swift cost indices for 1973 and 1975 gives:

$$\frac{443.8}{344.1} \times \$10,000 = \$12,900$$

Initial Carbon Charge - As recommended by Hutchins (1975a) each of three contactors would have an initial charge of 12,000 lb of granular activated carbon (Hydrodarco 4,000, ICI, United States, Inc.) at a cost of $0.38/lb. Then,

$$3 \times 12,000 \times \$0.38 = \$13,700$$

Summary of Capital Investment - Plant investment costs for the carbon adsorption equipment are:

	Estimated Installed Costs (1975 $)
Influent pump station	$ 12,900
Carbon contactors (3)	209,800
Initial carbon charge	13,700
Subtotal	$236,400
Adjustment to account for engineering, legal, administrative land and interest expenses, 20% of subtotal (Cornell, 1973)	47,000
Total	$283,400

Capital Investment Costs for Carbon Adsorption Unit with 60 Min Contact Time

At 300 gpm, a 30 min contact time in each carbon adsorber corresponds to a holding volume per vessel of 300 x 30 = 9,000 gal. or 1,204 ft^3. Cornell (1973) recommends 50% additional adsorber volume to provide for backwash operation. Thus, the total volume of each vessel would be 1.5 x 9,000 or 13,500 gal. For a flow rate of 4 gpm/ft^2, the cross-sectional area of each contactor would be $\frac{300}{4}$ = 75 ft^2 and the effective volume would be 2 x 522 or 1,044 ft^2.

Cost data by Cornell (1973) show that the cost for a contactor with 1,044 ft^3 of effective volume is about $80,000. For three contactors, the cost is 3 x $80,000 or $240,000. Updating by Marshall and Swift cost indices for 1975 and 1973 gives:

$$\frac{443.8}{344.1} \times \$240,000 = \$309,500$$

The initial carbon charge would be twice as large as for the 30 min total contact system or 2 x $13,700 = $27,400.

It is considered that the influent pump station cost would be the same as for the 30 min contact system or $12,900.

Summary of Capital Investment - Estimated plant investment costs for the carbon adsorption equipment are:

Item	Estimated Installed Costs (1975 $)
Influent pump station	$ 12,900
Carbon contactors (3)	309,500
Initial carbon charge	27,400
Subtotal	$349,800

Adjustment to account for engineering, legal, administrative, land and interest expenses; 20% of subtotal (Cornell, 1973)	$ 70,000
Total	$419,800

Operating Labor and Maintenance - Operating labor time is taken to be the same as for the 30 min contact system or 510 man-hours/year.

The annual maintenance cost for the carbon adsorption operation is estimated as 5% of capital investment (see Appendix A) as 0.05 x $419,800 = $21,000.

Other Operating Costs - All other operating costs were calculated by the same procedure as used in the estimate for a 30 total contact time as described in the preceding subsections.

Annual Operating Cost for Carbon Adsorption System (Including Sedimentation, Filtration, and Neutralization)

The total annual costs to operate the system at the 300 gal/min flow rate are estimated below. Most of these costs are a percentage of either the installed capital equipment cost or the labor costs previously described. The following list shows all of the cost items considered in this estimate.

Direct costs

Materials
Labor
Supervision
Payroll charges
Maintenance
Operating supplies
Utilities
Laboratory services

Indirect costs

Depreciation
Property taxes
Insurance
Capital cost
Plant overhead

Operating Labor and Maintenance for Carbon Adsorption Plant - Operating labor time is estimated from cost data reported by Cornell (1973) (Figure 5-7, p. 5-18). The flow (432,000 gpd) for the conceptual carbon adsorption system is off-scale on Figure 5-7. The one-fourth factor (see Appendix A) is used to scale down labor requirements from one plant size to a smaller plant size. From Figure 5-7 (Cornell, 1973), the operating labor requirement for a flow of 2 MGD is 750 annual man-hours. Scaling down this value by the one-fourth factor (see Appendix A) gives:

$$750 = \left(\frac{2}{0.432}\right)^{0.25} C$$

C = 510 man-hours for a flow of 0.432 M gpd (300 gpm)

The annual maintenance cost for the carbon adsorption operations is estimated to be 5% of the capital investment (see Appendix A) or 0.05 x $283,400 = $14,200.

Materials - The only material costs of any consequence are the sodium carbonate used to neutralize the wastewater and the activated carbon make-up. These costs have been previously given.

Labor - Labor costs are wages paid to operating labor. The total annual operating labor required for the plant is:

Process	Annual man-hours
Sedimentation	1,050
Filtration	1,050
Neutralization	1,050
Carbon adsorption	510
Total	3,660

The hourly earnings of production or nonsupervisory workers in the chemical and allied products industry was $5.18/hr in March 1975 (Monthly Labor Rev, May 1975). For April 1975, the estimated wage rate is $5.20/hr. This gives an annual operating labor cost of $19,000.

Supervision - Supervision of labor is normally estimated as a percentage of operating labor, a typical value being 20% (Jelen, 1970). Using this typical value of 20% of operating labor costs for labor supervision costs gives a cost of $3,800/year.

Payroll Charges - This cost is the result of the many fringe benefits employees receive in addition to their salaries. Recent emphasis on these benefits in labor contracts make this cost substantial and it is steadily increasing with time. The sum of fringe benefits may add between 15 and 40% to the wage rate of employees (Perry, 1973), and this varies widely from company to company. In this estimate, payroll charges (fringe benefits) are taken to be 30% of the wages paid to both labor and supervision. This cost amounts to $6,800.

Maintenance - Maintenance costs have been determined previously for each part of the process. They are summarized here to give the total annual plant maintenance costs.

Process	Annual maintenance
Sedimentation	$ 5,000
Filtration	7,900
Neutralization	2,900
Carbon adsorption	14,200
Total	$30,000

Operating Supplies - Operating supplies are items such as lubricating oil, instrument charts, etc., that are neither raw or repair materials. The cost of these items is typically 6% of labor costs (Jelen, 1970), and amounts to an annual cost of $1,100.

Utilities - The utilities required for the process are primarily electrical power. The estimated annual electrical cost for this system estimated from cost data reported by Cornell (1973) (Figure 5-9, p. 5-20). Figure 5-9 shows an annual power cost (at $0.02/KWH) of 4,600/year. Adjusting from 1973 to 1975 by Marshall and Swift cost indices for electrical power industries gives $\frac{437.7}{322.2} \times 4,600 = \$6,200$.

Laboratory - Laboratory services furnished to support the treatment process operation are estimated at 20% of labor cost (Jelen, 1970) or $3,800/year.

Depreciation - Depreciation is a periodic charge that distributes the installed capital investment cost over its expected service life. This cost estimate uses straight line depreciation and assumes all capital assets have a zero salvage value. The capital investment costs and expected lives of all depreciable assets have been previously given and are summarized and totaled below (rounded to nearest $100):

Process	Life (year)	Annual depreciation cost ($)
Sedimentation	40	800
Filtration	15	10,500
Neutralization	10	5,800
Carbon adsorption	10	28,300
Total		45,400

Property Taxes, Insurance, and Capital Costs - Property taxes, insurance and capital costs are estimated as a percentage of the installed capital equipment cost. These costs are calculated and reported in this report separately to show the cost breakdown of these three items.

Property taxes are taken to be 2% of investment cost, and insurance is generally about 1% of investment cost (Jelen, 1970). Capital cost (or interest) is a charge to finanace the investment expenditures. This interest may be a real cost when funds are borrowed to finance the investment, or an assumed cost when internal funds are used (since internal funds would earn interest if loaned out rather than purchase capital assets). The annual rate of interest has varied widely in the recent past and is taken to be 6.3% per annum for 10 years (see Appendix A).

Using the above percentages gives the following indirect costs for this system:

Cost item	Annual cost ($)
Property taxes (2%)	13,800
Insurance (1%)	6,900
Capital cost (6.3%)	43,600

Plant Overhead - Plant overhead is a charge to the costs of the manufacturing facility which are not chargeable to any particular operation and are normally charged on an allotted basis. Overhead includes such cost items as plant supervision, plant guards, janitors, cafeterias, administrative offices, accounting, purchasing, etc. Overhead costs will vary from company to company and are usually calculated as a percentage of direct labor or a percentage of installed capital investment for the entire facility, and allocated to each operation based on its labor or investment cost.

Plant overhead can range from 40 to 60% of direct labor costs or 15 to 30% of direct costs (Jelen, 1970). We estimate that plant overhead is 20% of direct costs in this report.

Total Costs for Carbon Adsorption System (Including Costs of Sedimentation, Filtration, and Neutralization)

The total cost of the carbon adsorption system is the sum of the total capital investment costs plus the annual operating cost. These costs have been estimated in the preceding three sections of this report.

The total estimated capital investment costs for the carbon adsorption system are presented in Table 5.

The estimated total investment and annual operating costs for the entire system are presented in Table 6.

Table 5. INSTALLED CAPITAL EQUIPMENT COST FOR THE 300 GPM CARBON ADSORPTION SYSTEM

Process	Capital investment cost (1975 $) Contact time 30 min	Contact time 60 min
Sedimentation	33,000	33,000
Filtration	158,000	158,000
Neutralization	58,200	58,200
Carbon adsorption	283,400	419,800
Subtotal	532,600	669,000
Contingency, 30% (see Appendix A)	159,800	201,000
Total	692,400	870,000

Table 6. ESTIMATED TOTAL INVESTMENT AND ANNUAL OPERATING COSTS FOR GRANULAR ACTIVATED CARBON ADSORPTION SYSTEMS (300 gpm Endrin Wastewater Flow Rate)

Carbon adsorption system total contact time, min	Costs $ (1975) 30	60
Cost item		
Total installed capital equipment cost	692,000	870,000
Annual operating costs,		
Direct costs		
Materials	7,600	7,600
Operating labor	19,000	19,000
Supervision	3,800	3,800
Payroll charges	6,800	6,800
Maintenance	30,000	36,800
Operating supplies	1,100	1,100
Utilities	6,200	6,200
Laboratory charges	3,800	3,800
Subtotal (rounded)	78,300	85,100
Indirect costs		
Depreciation	45,400	59,100
Property taxes and insurance	20,700	26,100
Capital cost (interest)	43,600	54,800
Plant overhead	15,700	17,000
Subtotal (rounded)	125,400	157,000
Total	203,700	242,100
Unit operating costs		
Cost ($)/1,000 gal. effluent	$1.35	$1.60
Cost, cents per pound of endrin produced (estimated 6 million pounds produced in 1975)	3.4¢	4.0¢

REFERENCES

Blecker, H. G., and T. M. Nichols, "Capital and Operations Costs of Pollution Control Equipment Modules--Vol. II--Data Manual," EPA-R5-73-023b, July 1973.

Chemical Engineering, "Economic Indicators," July 7, 1975a.

Chemical Engineering, p. 89, July 21, 1975b.

Chemical Marketing Reporter, April 28, 1975.

Cornell, Howland, Hayes, and Merryfield, Clair A. Hill and Associates, "Process Design Manual for Carbon Adsorption," U.S. EPA, October 1973.

Cywin, A., Director, Effluent Guidelines Division, letter to Mr. D. R. Marks, Technical Superintendent, Velsicol Chemical Corporation, Memphis, Tennessee, March 12, 1975.

Cywin, A., and E. E. Martin, "Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Major Inorganic Products Segment of the Inorganic Chemicals Manufacturing Point Source Category," September 1973.

Envirogenics Systems Company, "Development and Demonstration of Process for the Treatment of Chlorinated Cyclodiene Pesticide Manufacturing and Process Wastes," December 1973.

Envirogenics Systems Company, "Development of Treatment Process for Chlorinated Hydrocarbon Pesticide Manufacturing and Process Wastes," Report No. L-0305-25, EPA Contract No. 68-01-0083, May 1974a.

Envirogenics Systems Company, "Status of Developments of Reductive Degradation Treatment of Endrin-Heptachlor and Chlordane Manufacturing Wastes," EPA Contract No. 68-01-0083, September 1974b.

Ferguson, T. L., and A. F. Meiners, "Wastewater Management Review No. 2--Endrin," Final Report, EPA Contract No. 68-01-2579, to the Hazardous and Toxic Substances Regulation Office, May 8, 1974.

Hager, D. G., "Industrial Wastewater Treatment by Granular Activated Carbon," Industrial Water Engineering, p. 14, January/February 1974.

Hager, D. G., and J. L. Rizzo, "Removal of Toxic Organics from Wastewater by Adsorption with Granular Carbon," paper presented at the Environmental Protection Agency Technology Transfer Session on Treatment of Toxic Chemicals, Atlanta, Georgia, April 19, 1974.

Hutchins, R. A., Development Associate, ICI United States, Inc., letter and telephone communication to Mr. C. E. Mumma, October 1975a.

Hutchins, R. A., "Activated Carbon Regeneration: Thermal Regeneration Costs," Chemical Engineering Progress, 71(5):80 (1975b).

Jelen, F. C., Cost and Optimization Engineering, McGraw-Hill Book Company, New York (1970).

Kennedy, D. C., "Treatment of Effluent From Manufacture of Chlorinated Pesticides With A Synthetic, Polymeric Adsorbent, Amberlite XAD-4," Environmental Science and Technology, 7(2):138 (1973).

Marks, D. R., "Testimony of Daniel R. Marks Respecting Technology to Remove Endrin From Water," FWPCA (307) Docket No. 1, State of Tennessee, County of Shelby, March 14, 1974a.

Marks, D. R., "Status Report on Chlorinated Hydrocarbon Pesticide Removal From Wastewater," EPA Grant No. S-803159-01-0, Velsicol Chemical Corporation, Memphis, Tennessee, September 30, 1974b.

Marks, D. R., "Chlorinated Hydrocarbon Pesticide Removal From Wastewater," EPA Grant 803159-01, Velsicol Chemical Corporation, February 1975a.

Marks, D. R., "Chlorinated Hydrocarbon Pesticide Removal From Wastewater," EPA Grant 803159-01, Velsicol Chemical Corporation, May 1975b.

Modern Cost--Engineering Techniques, p. 252, McGraw-Hill Book Company, New York (1970).

Monthly Labor Rev., Vol. 98, No. 5, May 1975.

Oil, Paint and Drug Reporter, November 27, 1972.

Perry, R. H., and C. H. Chilton, Chemical Engineer's Handbook, 5th Ed., McGraw-Hill Book Company, New York (1973).

Richardson, L. T., and D. M. Miller, "Fungitoxicity of Chlorinated Hydrocarbon Insecticides in Relation to Water Solubility and Vapor Pressure," Canadian Journal of Botany, 38:163 (1960).

Robeck, G. G. et al., "Effectiveness of Water Treatment Process in Pesticide Removal," J. Amer. Water Works Assn., 57:181 (1965).

Ryckman, Edgerlin, Tomlinson, and Associates, Inc., "Pesticide Poisoning of Pond Lick Lake, Ohio. Investigation and Solution," Environmental Protection Agency, Office of Water Programs, Oil and Hazardous Materials Program Service, OHM, 71-06-002 (1971).

Sweeny, K. H., and J. R. Fischer, "Investigation of Means for Controlled Self-Destruction of Pesticides," Aerojet Final Report on FWQA Contract No. 14-12-596, Water Pollution Control Research Series 16040 ELO 06/70, June 1970.

Sweeny, K. H., and J. R. Fischer, "Decomposition of Halogenated Organic Compounds Using Metallic Couples," U.S. Patent No. 3,737,384, for U.S. Department of the Interior, June 1973.

Swank, R. R., Jr., Acting Chief, Industrial Pollution Branch, Southeast Environmental Research Laboratory, Athens, Georgia, Site visit by A. F. Meiners and C. E. Mumma, September 29, 1975.

Vitalis, J. S., "Velsicol Plant Notes Summary," Record of Communication to Walter J. Hunt, Chief, Effluent Guidelines Development Branch, June 2, 1975.

Weston, Roy F., Inc., Draft, "Development Document for Effluent Limitations Guidelines and Standards of Performance - Miscellaneous Chemicals Industry," EPA Contract No. 68-01-2932, February 1975.

APPENDIX A

DEFINITION OF TERMS AND DISCUSSION OF CONVENTIONAL ENGINEERING PRACTICES USED IN ESTIMATING COSTS OF PESTICIDE WASTEWATER TREATMENT PROCESSES

Several terms used in the cost estimates require further definition and have been placed in this appendix to avoid a lengthy discussion in the text of the report. The terms which are defined and discussed in this appendix are (a) limits of error for cost estimates, (b) cost indexes, (c) six-tenths factor, (d) one-fourth factor, (e) payroll charges, (f) operating supplies, (g) control laboratory costs, (h) maintenance and repairs, (i) depreciation, (j) capital cost, (k) plant overhead, and (l) contingency for capital investment.

LIMITS OF ERROR FOR COST ESTIMATES

The probable limits of error for the study cost estimates in this report range from 30% above to 30% below the actual costs. Study cost estimates are commonly used to estimate the economic feasibility of a project before expending significant funds for piloting, market studies, land surveys, and requisitions. They may be off by 30% but they can be prepared at relatively low costs using minimum data as follows (see Figure A-1).

Location of site;

Rough sketches of process flow;

Preliminary sizing and material specifications of equipment;

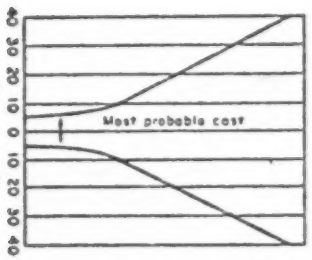
Approximate sizes of buildings and structures;

Rough quantities of utilities;

Preliminary piping;

Preliminary motor list; and

Engineering and drafting man-hours.



Reproduced from best available copy.

Required information	Firm estimate ±5% range	Project control estimate ±10% range	Budget authorization estimate ±20% range	Study estimate ±30% range	Order-of-magnitude estimate ±50% range	
Location	•	•	•	•		Site
General description	•	•	•			
Soil bearing	•	•	•			
Location & dimensions RR, roads, impounds, fences	•	•	•			
Well-developed site plot plan & topographical map	•	•				
Well-developed site facilities	•					
Rough sketches				•		Process flow sheet
Preliminary			•			
Engineered	•	•				
Preliminary sizing & material specifications			•	•		Equipment list
Engineered specifications	•	•				
Vessel sheets	•	•				
General arrangement						
(a) Preliminary		•	•			
(b) Engineered	•					
Approximate sizes & type of construction			•	•		Building and structures
Foundation sketches		•	•			
Architectural & construction	•	•	•			
Preliminary structural design			•			
General arrangements & elevations	•	•				
Detailed drawings	•					
Rough quantities (steam, water, electricity, etc.)				•		Utility requirements
Preliminary heat balance			•			
Preliminary flow sheets			•			
Engineered heat balance	•	•				
Engineered flow sheets	•	•				
Well-developed drawings	•					
Preliminary flow sheet & specifications			•	•		Piping
Engineered flow sheets	•	•				
Piping layouts & schedules	•					
Rough specifications			•			Insulation
Preliminary list of equipment & piping to be insulated		•				
Insulation specifications & schedules	•	•				
Well-developed drawings or specifications	•					
Preliminary instrument list			•			Instrumentation
Engineered list & flow sheet	•	•				
Well-developed drawings	•					
Preliminary motor list—approximate sizes			•	•		Electrical
Engineered list & sizes	•	•				
Substations, number & sizes, specifications	•	•	•			
Distribution specifications	•					
Preliminary lighting specifications			•			
Preliminary interlock, control, & instrument wiring specs		•				
Engineered wiring diagrams (power & light)	•	•				
As-constructed drawings	•					
Engineering & drafting	•	•	•	•		Man-hours
Labor by craft	•					
Supervision	•					
Product, capacity, location & site requirements. Utility & service requirements. Building & auxiliary requirements. Raw materials & finished product handling & storage requirements					•	Typical cost of standard processes

Figure A-1. Estimating Information Guide

COST INDEXES (Peters and Timmerhaus, 1968)

Most cost data which are available for immediate use in a preliminary or predesign estimate are based on conditions at some time in the past. Because prices may change considerably with time, due to changes in economic conditions, some method must be used for converting costs applicable at a past date to equivalent costs that are essentially correct at the present time. This can be done by the use of cost indexes.

A cost index is merely a number for a given year showing the cost at that time relative to a certain base year. If the cost at some time in the past is known, the equivalent cost at the present time can be determined by multiplying the original cost by the ratio of the present index value to the index value applicable when the original cost was obtained.

$$\text{Present cost} = \text{original cost} \frac{\text{index value at present time}}{\text{index value at time original cost was obtained}}$$

Cost indexes can be used to give a general estimate, but no index can take into account all factors, such as special technological advancements or local conditions. The common indexes permit fairly accurate estimates if the time period involved is less than 10 years.

Many different types of cost indexes are published regularly.

Engineering News-Record Construction Cost Index

Relative construction costs at various dates can be estimated by use of the Engineering News-Record construction index. This index shows the variation in labor rates and materials costs for industrial construction. It employs a composite cost for 2,500 lb of structural steel, 1,088 fbm of lumber, 6 bbl of cement, and 200 hr of common labor. The index is usually reported on one of three bases: an index value of 100 in 1913, 100 in 1926, or 100 in 1949.

Marshall and Swift (Formerly Marshall and Stevens) Equipment-Cost Indexes

The Marshall and Stevens equipment indexes are divided into two categories. The all-industry equipment index is simply the arithmetic average of the individual indexes for 47 different types of industrial, commercial, and housing equipment. The process-industry equipment index is a weighted average of eight of these, with the weighting based on the total product value of the various process industries. The percentages used for the weighting in a typical year are as follows: cement, 2; chemicals, 48; clay products, 2; glass, 3; paint, 5; paper, 10; petroleum, 22; and rubber, 8.

The Marshall and Stevens indexes are based on an index value of 100 for the year 1926. These indexes take into consideration the cost of machinery and major equipment plus costs for installation, fixtures, tools, office furniture and other minor equipment.

Chemical Engineering Plant Construction Cost Index

Construction costs for chemical plants form the basis of the Chemical Engineering plant construction cost index. The four major components of this index are weighted in the following manner: equipment, machinery, and supports, 61; erection and installation labor, 22; buildings, materials, and labor 7; and engineering and supervision manpower, 10. The major component, equipment, is further subdivided and weighted as follows: fabricated equipment, 37; process machinery, 14; pipe, valves, and fittings, 20; process instruments and controls, 7; pumps and compressors, 7; eletrical equipment and materials, 5; and structural supports, insulation, and paint, 10. All index components are based on 1957 to 1959 = 100.

SIX-TENTHS FACTOR (Perry and Chilton, 1973)

Cost estimates in this report are given for processes that require scaling up from a given capacity to a larger capacity (e.g., 100 gpm to 300 gpm and 600 gpm). Equipment size and costs were shown to correlate fairly well by the logarithmic relationship known as the "six-tenths factor." The simple form of this method is:

$$C_n = r^{0.6} C$$

where C_n is the new plant cost, C is the previous plant cost, and r is the ratio of the new capacity to the old capacity.

This method is the best available for estimating the cost of the systems in this report since each system involves multiple pieces of equipment, piping, instrumentation, etc. The exponent actually ranges from

0.45 to 1.15 for different pieces of equipment, but in complex systems, such as the ones described in this report, estimating the new capacity cost for each piece of equipment is beyond the scope of this study.

Therefore, when scaling the costs up, for example, from a 100 gpm plant size to other plant sizes, the exponent 0.6 is used as an approximation of the scale-up factor for the entire system. In each case, some error may be involved using this method, but no other method is available for this study.

ONE-FOURTH FACTOR (Peters and Timmerhaus, 1968)

The "one-fourth factor" uses the same principle as the "six-tenths factor" with the exception that the exponent 0.25 is used instead of 0.6. This factor is used to scale up labor requirements from one plant size to a larger plant size, and takes into account the fact that larger plant sizes require less than proportional labor forces due to economies of scale.

PAYROLL CHARGES

These costs are the result of the many fringe benefits employees receive in addition to their salaries. Recent emphasis on these benefits in labor contracts make this cost substantial and it is steadily increasing with time. The sum of fringe benefits may add between 15 and 40% to the wage rate of employees (Perry and Chilton, 1973), and the percentage varies widely from company to company. In this report, payroll charges (fringe benefits) are estimated to be 30% of the wages paid to both labor and supervision.

OPERATING SUPPLIES

Operating supplies are items such as lubricating oil, instrument charts, etc., that are neither raw nor repair materials. The cost of these items is typically about 6% of operating labor (Jelen, 1970).

CONTROL LABORATORY COSTS

Depending on company practice and the type of project, operating costs may include several charges by other units of the company, e.g., charges by a control laboratory.

Laboratory costs may be estimated as a percentage of operating labor cost, in the range of 3 to 10%, but the complex situations as high as 20% (Jelen, 1970). Since treatment systems require more laboratory support than typical production processes, in this report the cost of these services is estimated to be 20% of operating labor costs.

MAINTENANCE AND REPAIRS (Peters and Timmerhaus, 1968)

A considerable amount of expense is necessary for maintenance and repairs if a plant is to be kept in efficient operating condition. These expenses include the cost for labor, materials, and supervision.

Annual costs for equipment maintenance and repairs may range from as low as 2% of the equipment cost if service demands are light to 20% for cases in which there are severe operating demands. The annual maintenance costs are given separately for each process in this report, and range from 5 to 15% of the capital equipment cost of the various processes.

DEPRECIATION

Depreciation is a periodic charge that distributes the installed capital investment cost over its expected service life. Instead of charging the cost of the equipment as an expense in the year of purchase, a portion of its cost is charged against revenues each year throughout its estimated useful life.

In this report the estimated useful life is determined by using the arithmetic average of the high and low lifetimes of equipment when a range is given, or 10 years if the useful life is unknown. In some cases, the useful life may be too high by U.S. Treasury Department Standard Guidelines (such as the 40-year life for the sedimentation process) which allows an 11 year depreciation for chemical plant equipment (Perry and Chilton, 1973). However, using 11 years for all equipment would either understate or overstate the real cost in most circumstances. When the useful life is unknown, 10 years is used to conform to the guidelines of the federal government.

A zero salvage value is assumed in all depreciation estimates and straight-line depreciation is used.

CAPITAL COST

Regardless of whether the capital investment is to be obtained from company funds or made available by bankers, it is logical that the invested capital earn a fair interest. If the company funds are not used

for the new unit, then they could be invested to bear a reasonable interest. If the capital is raised by issuing bonds or by borrowing from another corporation, interest would be paid the investor. It should be pointed out that in order to offer a company the incentive to invest its money in a new plant, it should be able to realize as large an interest rate as it could earn by making other investments. Since the risk is somewhat higher than certain conservative investments, the interest rate should be higher than that offered by these securities. Excessive interest rates are not realistic in view of today's regulatory laws. Normally, an interest rate of from 6 to 8% on the unpaid principal is considered satisfactory.

In computing interest, it is necessary to remember that the amount of interest will decrease each year since the unpaid balance is reduced by the depreciation allowed the previous year. An interest rate of 10% would average approximately 6.3% of the total principal each year if the principal is repaid in 10 annual installments. It is customary to express the interest as a uniform fixed cost item each year.

An interest rate of 10% is used in these estimates based on the cost literature (Chemical Engineering, 1975).

In reality, the interest will decline each year and, therefore, the payment on the principal will increase if uniform principal plus interest payments are made. Uniform payments for n periods required to pay the original sum P can be computed from the following equation (Petroleum Refiner, 1957).

$$R = P\frac{i(1 + i)^n}{(1 + i)^n - 1}$$

where P = original sum

R = uniform periodic payment

n = number of payments

i = interest rate as fraction per period

The expression $(1 - i)^n$ is the compound interest expression found in table form in many handbooks (Lange, Handbook of Chemistry). Value of $i(1 + i)^n/(1 + i)^n - 1$ for various values of n and i are listed below (Petroleum Refiner, 1957).

Values of $\frac{i(1 + i)^n}{(1 + i)^n - 1}$

n	2%	4%	6%	8%	10%
1	1.020	1.040	1.060	1.080	1.100
5	0.212	0.225	0.237	0.250	0.264
10	0.111	0.123	0.136	0.149	0.163

If the original investment was $1,000,000 and the loan was at 10% interest for 10 years, the uniform payment would be

$$R = (1{,}000{,}000)\frac{0.1(1 + 0.1)^{10}}{(1 + 0.1)^{10} - 1}$$

$$R = 163{,}000$$

In 10 years the total payment would be $1,630,000. Thus, the total interest is $630,000 and the average interest rate would be

$$\frac{630{,}000}{10(1{,}000{,}000)} = 6.3\%/\text{year}$$

PLANT OVERHEAD

Plant overhead is a charge to the costs of the manufacturing facility which are not chargeable to any particular operation and are normally charged on an allotted basis.. Overhead includes such cost items as plant supervision, plant guards, janitors, cafeterias, administrative offices, accounting, purchasing, etc. Overhead costs will vary from company to company and are usually calculated as a percentage of direct labor cost or a percentage of installed capital investment for the entire facility, and allocated to each operation based on its labor or investment cost.

Plant overhead can range from 40 to 60% of direct labor costs or 15 to 30% of direct costs (Jelen, 1970). We estimate that plant overhead is 20% of direct costs in this report.

CONTINGENCY FOR CAPITAL INVESTMENT (Fowler, 1975)

The selection of a contingency figure for an estimate is a matter of the judgment of the estimator. This judgment must consider several factors, such as:

(1) Data basis--laboratory, pilot or plant

(2) Allowance for inflationary trends

(3) Knowledge of construction costs at plant location

Under favorable conditions, the contingency factor may be as low as 10%. However, lacking actual plant cost and considering present inflationary trends, a contingency figure of 30% would be justified.

In the past, cost indexes have been a reliable method of estimating cost based upon plant costs in earlier years. The plant indexes are more reliable when used on plant cost rather than pilot plant costs. It is much more difficult to use them successfully when equipment is pilot plant size or when a small amount of equipment is used. The use of the indexes in the last 2 years has not been as accurate as in the past and can result in too low a plant estimate. Uncertainty increases if cost indexes are used to update plant estimates rather than actual costs.

Unless the estimator has made the original estimate or knows what the plant costs include, a large amount of uncertainty exists when projecting plant costs to other plant capacities and times. It is necessary to know whether a plant investment includes the cost of utilities, such as a steam boiler or cooling tower, or whether steam and utilities are available at the battery limits of the unit in any amount required. It is also important to know whether the plant investment includes the cost of the land and site preparation. Only if these factors are known can the contingency factor be kept to a reasonable figure of 30% or lower.

REFERENCES

1. Chemical Engineering, p. 89, July 21, 1975.

2. Fowler, F. C., Chemical Engineering Consultant to Midwest Research Institute and President of Research Associates, Kansas City, Missouri, Personal Communication to C. E. Mumma, October 15, 1975.

3. Jelen, F. C., Cost and Optimization Engineering, McGraw-Hill Book Company, New York (1970).

4. Perry, R. H., and C. H. Chilton, Chemical Engineers Handbook, 5th Ed., McGraw-Hill Book Company, New York (1973).

5. Peters, M. S., and K. D. Timmerhaus, Plant Design and Economics for Chemical Engineers, McGraw-Hill Book Company, 2nd Ed. (1968).

6. Petroleum Refiner, Process Design Primer, September 1957.